PRACTICAL HELPS

FOR THE ELECTRIC RAILWAY SHOP, TRACK, POWER, LINE AND ROLLING STOCK DEPARTMENTS

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FOREWORD

Something over a year ago the *Electric Railway Journal* began the publication of its monthly "Mechanical and Engineering Numbers." The purpose of these has been to furnish articles of a character particularly helpful to the men who are responsible for the upkeep of the physical equipment of an electric railway property. Overhead line construction, tracks, buildings, power plants, substations, shops and rolling stock and its equipment have all been kept in mind.

Arrangements were made with several specialists in different parts of the electric railway field for series of articles covering the fundamentals of track, power transmission, car equipment, car bodies and power plant operation; these were in addition to numerous articles on details of practice in the several lines mentioned. While all of the series are not yet complete, they have proved to date so valuable and comprehensive that the publishers of the paper have decided to reprint a number of the articles in the several series, particularly for the benefit of those who have not had the opportunity to read them month by month. Space limitations have prevented the reprinting of the entire groups of articles but a careful selection has been made of those which seem to have greatest immediate practical value. Readers of this volume are referred to the original series in each of the fields if further details are desired.

The authors of the articles reprinted are all qualified by practical experience and theoretical study to furnish the kind of material desired by the workers in the "practical" departments of the electric railways. For want of a better word the term "practical" is used to designate those who have to do with physical equipment. Mr. Cram is in daily contact with the way and structure problems of the Brooklyn Rapid Transit System and had a wide experience before joining the staff of the B. R. T. Mr. Harte, construction engineer of the Connecticut Company, has particularly to do with new work on a large railway system, being especially interested in power transmission problems.

He is very active in the standardization work of several technical societies. Mr. Litchfield, when he commenced his series on car design, was connected with the Interborough Rapid Transit Company, New York City, later joining the technical staff of the American Car & Foundry Company. He has specialized particularly on the structural features of the electric railway car, but has had broad experiences in other parts of this field. Mr. Smith, now connected with the New England Power Company, was until recently head of the Bureau of Tests of the Brooklyn Rapid Transit System. Here he had to do with all phases of power plant operations in so far as they effected economy and reliability. His articles were based particularly upon his testing experience. Mr. Squier, when he began his series, was an engineer with the Public Service Commission of New York State, First District; this commission has jurisdiction in the city of Greater New York. Previously he had been connected with the mechanical department of the Brooklyn Rapid Transit Company and had served on the engineering staff of the General Electric Company. He is now a member of the editorial staff of this paper. These brief notes regarding the authors whose articles are reprinted in this volume will serve, using a legal term, "to qualify them as experts." Further than this we shall let the articles speak for themselves.

EDITORS,
Electric Railway Journal.

April 20, 1919

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PART I

TRACK AND STRUCTURES

By R. C. Cram, Assistant Engineer Way and Structure Department, Brooklyn Rapid Transit System

PRACTICAL HELPS

FOR THE ELECTRIC RAILWAY SHOP, TRACK, POWER, LINE AND ROLLING STOCK DEPARTMENTS

CHAPTER I

WHAT THE MAINTENANCE OF WAY DEPARTMENT DOES

THERE is no standard book on modern electric railway track construction and maintenance to which the young engineer or student can refer for information. There are handbooks which treat the subject in a rather formal way as a part of the general subject of electric railways, but none of them begins to tell the whole story. They lack the essential features of co-ordination and sufficient elaboration. Similarly, the steam railroad track maintenance field was not covered by a book devoted entirely to the subject until Willard's work on "Maintenance of Way and Structures" appeared in 1915.

The electric railway track, particularly that in streets, is intimately connected with the nature of rolling stock, vehicular traffic and street pavements. It is a fundamental part of the railway, and has a vital influence in the operating and maintenance cost of the road. The location of the tracks, largely in streets or highways, is responsible for the principal differences between electric railway track and steam railroad track, and contributes many details of construction and maintenance expenses which the steam road escapes.

The materials, appliances and methods used in electric railway track maintenance have entered upon a new phase, which began about 1908, principally as the result of extraordinary replacements required by much trackage reaching its wear limit.

During the life of the electric railway the track has passed through a cycle which has attempted to follow the rapid changes in type and weight of rolling stock. It began with the light electrified horse car running on "tram" or stringer rails in cobble pavement. These were succeeded by the double-truck car whose weight steadily increased up to 35,000 or 40,000 lb., and the rails were changed to deep girder sections on ties in rough 8-in. granite or other block pavements. The recent tendency in rolling stock is in the nature of a return to the light-weight car, often of the single-truck type, and the track construction is returning to rails of less depth and sometimes of less weight. The pavement is tending toward the smooth types, such as asphalt and other bituminous pavements, 4-in. grouted, granite, concrete and brick. Along with these changes in rolling stock and track, the character of vehicles using the streets has been changing. The narrow steel-tired wagon wheel of the horse-drawn vehicle is being supplanted by the rubber-tired motor vehicle, with a consequent lessening of the destructive action upon track pavements.

In company with these developments, much attention has been directed toward the materials of construction, and there has been a crystallizing force at work in the track-maintenance organizations so that they are rapidly approaching quite similar lines of endeavor.

It is believed that the work as now conducted will admit of description, and in this attempt to co-ordinate available data an effort will be made to set forth the best accepted practice now current in that important branch of electric railway engineering which has come to be known as maintenance of way and structures. Advantage will be taken of the privileges enjoyed in co-operation with other maintenance engineers through joint service for several terms as a member of the committee on way matters of the American Electric Railway Engineering Association. The Engineering Manual and Proceedings of that association will be drawn upon frequently, as it is responsible in a large measure for the standards now existing in electric railway engineering practice.

The similarity which modern interurban and high-speed tracks have to steam-road tracks makes the work of the American Railway Engineering Association particularly valuable to electric

railway engineers, and the material from its proceedings as coordinated in Willard's work on "Maintenance of Way and Structures" will be used as occasion warrants. The valuable reports of the Board of Supervising Engineers, Chicago Traction, will also be consulted freely, since the reports cover many original investigations made in conjunction with the practical reconstruction of the entire surface railway system in Chicago, now about finished.

The work of others, and of periodicals, societies and associations, will also be credited where credit is due.

Maintenance of Electric Railway Track Is a Big Task. In round numbers there were 50,000 miles of single track operated by 1029 electric railway companies in the United States on June 30, 1917. This mileage is about 12 per cent of the steam-railroad mileage as of January, 1918, and is greater by about 9000 miles than the entire steam-road mileage of the Dominion of Canada in 1914. The electric railway trackage in operation would provide a double-track railroad around the earth at the equator. About 300,000 people were employed in operating and maintaining electric railways in the United States in 1917.

The upkeep of 50,000 miles of electric railway track, about 60 per cent of which is in densely populated areas within cities or towns (which means that this trackage is generally well paved) presents a problem worthy of the best engineering talent. The work involved is so full of detail as compared with steam-railroad maintenance work, that the force required by the electric railways could probably maintain more than twice as much mileage if employed in steam-road service. In common with the latter service, the work is termed "Maintenance of Way and Structures" or sometimes simply "Maintenance of Way." Its importance is indicated by the records, which show that about 16 per cent of the total operating expense is on maintenance of way and structures. The track is the basis part of an electric railway property, and because of its usual location in streets its maintenance must require a high order of skill, judgment and executive ability, and often considerable diplomacy, particularly in dealings with numerous civic authorities. Organization also plays a big part in the successful conduct of the work.

It should be remembered, as Willard has well said, that "two important facts should be understood, viz.: (1) The large pro-

portion of the operating expense which is expended in track *and pavement* maintenance; (2) the relation existing between the kind, *location* and condition of the track and the economical operation and business of the road.'' (The italics are the writer's.)

The track, pavement and roadbed represent the greater part of the investment in such roads, as a rule, yet the maintenance of this part of the property as a branch of engineering has not been recognized until recently as being of any particular degree of importance.

In line with steam road history, the work in the past was often in the hands of the practical man who had worked up from the ranks. In recent years, the necessity for the proper recognition of the importance of the work has been more and more apparent, so that to-day quite a number of roads have cadet engineers in training for the work, and we now generally have the engineer of maintenance of way replacing the old-time roadmaster or general foreman.

The tendency of electric railway managements to disregard the recommendations of the way department is perhaps not so pronounced as it is in steam-road practice. Nevertheless, when it seems necessary to reduce expenses the way department is generally the first one to receive the axe of retrenchment, and usually at a time when the performance of the work could be done most economically.

This is particularly true of the spring season, when much work should be completed before the heavy rush of midsummer business. The fact that cars must be operated and service maintained, with the necessary maintenance of equipment and operation of power plants, makes it plain as to why the way department must suffer first in consequence of any policy of economy. Such economies, however, are expensive in the end, as the usual result is a heavier proportionate expense later. Combined with this are increased expenses in maintenance of equipment, overhead line and transportation. These follow because track deteriorates rapidly if not well maintained, and rough track, bad joints and poor bonding soon cause excessive damage to equipment, extraordinary side wear on trolley wire, increased power consumption, and even the reduction of car speed in sufficient amount to require more cars to operate the line.

There is little doubt that the hitherto prevailing time for closing the financial year coming in June, as it has for a long period, has been responsible for the enforcement of retrenchment policies during the best part of the working season. However, the movement is gaining headway, and has been sanctioned by the various regulatory bodies which provides for an agreement between the financial year and the calendar year. The effect of this change will be appreciated by all having charge of maintenance-of-way matters.

It is believed that most managements now realize the importance of two basic principles: (1) The need for continued minor repairs and renewals to keep the track and pavement up to some fixed standard to offset normal wear and tear or depreciation; and (2) the need for a certain minimum amount of reconstruction or extraordinary maintenance to keep up a reasonable balance between traffic increases and increased loading or excessive wear on some portions of the system.

Improvements That Are Suggested by the Way Engineer. It is clearly the duty of the way engineer to point out to the management such improvements in tracks and structures as conditions may suggest, and from time to time to make requests for appropriations of funds to carry out the work desired. It is also his duty to make the best possible use of the moneys assigned for such improvements. He must, in addition, be prepared to furnish plans and estimates for the various improvements, additions and betterments which are constantly being brought forward by the operating officials. These projects take the form of suggestions for double tracking, changes in special trackwork for re-routing of cars, construction of additional sidings and turnouts on single-track roads, and sometimes grade reductions and changes in alignment. The betterment and changes in bridges and other structures are also items which require a great deal of attention, with the view of securing all possible economies in maintenance charges. There are many municipal and state projects which require the engineer's most careful attention because of the necessity for co-operation with public authorities in connection with public improvements. It is not the purpose of these articles to discuss these improvements, except to point out occasionally how neglect of consideration of the maintenance point of view, when improvements and con-

struction work are being planned, may ultimately provide excessive charges for maintenance.

Maintenance Never Stops. The construction of an electric railway is naturally of first importance, but once the road is finished its maintenance begins. The construction period is comparatively short, while the maintenance period never ceases unless the road is abandoned. Consequently the work of the maintenance-of-way department may be said to assume first importance so soon as the construction department ceases its activities. This is particularly true in electric railway work, because new construction is and has been almost at a standstill for the last five years at least, and what little construction work has been done has usually been carried out by the engineer of maintenance of way, acting through a specially assigned construction engineer. In times of stress, construction work can be stopped entirely for comparatively long periods, but a reasonable amount of maintenance must go on so long as the road is in operation.

In common with steam roads, the proportion of maintenance expense to total operating expense is high. This has been assigned to the fact that, like the early steam roads, the electric railways were originally built rapidly, and often in undeveloped territory. They were also built with the view to cheapness in first cost rather than to economy in future maintenance. Furthermore, quite a long period of time was required for inherent defects in early construction to develop, and much trackage was built with these inadequate early types as patterns before the defects of such types could be determined. There was also a long period of constant and rapid increase in car weights and traffic, which finally reached the point where the track construction was really not strong enough to sustain the loading. Under these conditions it is to be expected that the maintenance costs would mount to high figures.

No Common Standard of Track Classification. The steam roads have adopted classifications of track construction which correspond to certain predetermined amounts of traffic and varying numbers of main tracks, and their standards of track construction and maintenance are based upon the classifications adopted by the American Railway Engineering Association, which are as follows:

Class A Track.—All districts of a railway having more than

one main track. Also all single-track districts where the traffic equals or exceeds a freight-car mileage of 150,000 per mile per year; or a passenger-car mileage of 10,000 per mile per year and a maximum passenger-train speed of 50 m.p.h.

Class B Track.—All single-track districts of a railway where the traffic is less than for Class A, and is equal to or exceeds a freight-car mileage of 50,000 per mile per year; or a passenger-car mileage of 5000 per mile per year and a maximum passenger-train speed of 40 m.p.h.

Class C Track.—All districts of a railway not meeting the traffic requirements of Classes A or B.

The modern interurban and high-speed electric railway construction, however, often meets and at times exceeds the requirements of Classes B and C in all respects except freight traffic, but there are no standard track classifications of this kind in the electric railway field. On the other hand, the electric railway is generally found to have only one fixed standard for its new construction or reconstruction in any one city or system covering a wide variation in traffic and disregarding the number of tracks. This applies to the interurban and other high-speed electric railways as well. It must not be understood that all the electric railway tracks on any one system or in any one city are alike. Far from it, because most properties of any considerable size are consolidations made up of different types of construction, which were perhaps selected by as many managements as there were companies. But it will be found that each system now has a fixed standard for city track and another for track on private way, and the attempt is being made to get the trackage rebuilt to only one or two general types for the system. This practice has both advantages and disadvantages, but the fundamental principles in back of it are sound, as they are based on many economies in materials and labor which accompany the use of only one or two standard types of construction.

What Does Electric Railway Track Cost? Electric railway track construction costs are subject to many variable conditions which will increase or decrease the cost over a wide range. There are at least five distinct types of roads, which in turn call for as many distinct differences in cost. These types are: (1) Urban or city lines; (2) interurban or suburban lines; (3) high-speed lines operated by means of third-rail or high voltage d.c.

and a.c. overhead trolley wires; (4) elevated railways, and, (5) subways. There is also a variation in strictly urban line costs, in New York and Washington, for instance, where the very expensive underground trolley system of operation is in use. Furthermore, the variation in character of country traversed and in cost of materials and labor in different parts of the country has considerable influence on costs.

Another factor which has a decided effect on the cost of urban or city lines is track pavement, which may vary as much as $10,000 per mile of track on lines similar in all other construction details, but situated in different cities, in one of which the paving requirements may call for a more expensive type of pavement than in the other.

In addition to these items, there are the variations in construction costs caused by the nature and extent of storage yards, terminal facilities at fair grounds, ferries, baseball parks and other places where large crowds of people congregate, and the important factor of special track work contributes cost variations which differ widely.

It is obvious that there can be no fixed rule governing the construction cost of electric railways, but it may be stated in a general way that, according to estimates by L. E. Fischer, the modern interurban road costs complete anywhere from $26,720 to $58,650 per mile of track (see Table I), and that the cost of

TABLE I—SUMMARY OF THE PRIMARY CONSTRUCTION COSTS FOR A PROPOSED ELECTRIC RAILWAY (FISCHER) [1]

Accounts	Cost per Mile of Track	
	Minimum	Maximum
1—Engineering and superintendence	$1,000	$2,000
2—Right-of-way	2,000	4,000
3—Other land used in electric railway operations	100	500
4—Grading	2,500	6,000
5—Ballast	1,500	4,500
6—Ties	1,820	2,600
7—Rails, rail fastenings and joints	3,700	4,200
8—Special work	400	600
9—Underground construction	....	....
10—Paving	....	....
11—Track laying and surfacing	800	1,200
12—Roadway tools	50	50

[1] See article by L. E. Fischer, on "Estimating Operating Expense and Cost of Construction," *Electric Railway Journal,* Sept. 6, 1913, page 387.

Accounts	Cost per Mile of Track Minimum	Maximum
13—Tunnels	....	....
14—Elevated structures and foundations	...	....
15—Bridges, trestles and culverts	2,000	4,000
16—Crossing, fences, cattle-guards and signs	500	1,000
17—Interlocking and other signal apparatus	....	2,500
18—Telegraph and telephone lines	100	500
19—Poles and fixtures	500	1,500
20—Underground conduits	....	....
21—Transmission system	500	1,200
22—Distribution system	1,500	5,000
23—Dams, canals and pipe lines	....	....
24—Power-plant buildings	600	1,200
25—Substation buildings	300	500
26—General office building	....	....
27—Shops and carhouses	400	600
28—Stations, waiting rooms and miscellaneous buildings	100	200
29—Docks and wharves	....	....
30—Power-plant equipment	2,000	4,500
31—Substation equipment	750	1,500
32—Shop equipment	150	300
33—Park and resort property	....	....
34—Cost of road purchased	....	....
35—Cars	800	2,600
36—Locomotives	....	....
37—Electric equipment of cars	600	1,600
38—Other rail equipment	200	500
39—Miscellaneous equipment	....	....
40—Law expenses	200	500
41—Interest	1,000	2,000
42—Injuries and damages	100	200
43—Taxes	50	100
44—Miscellaneous	500	1,000
Total	$26,720	$58,650

right-of-way, tracks, bridges, signals and incidental structures, other than overhead work, will range from $16,140 to $32,710 per mile of track (see Tables I and II). These estimated figures were for 1913, and were based on an analysis of costs for ten interurban roads.

Tracks on lines located entirely in cities or towns, and requiring pavement, will range in cost from $20,000 to $45,000 per mile of track. The latter figure is taken from actual costs of a 6-mile extension built in 1917 in a large Eastern city, while the former covers a 2-mile construction job done in 1914 in an Ohio town.

TABLE II—ESTIMATED TRACK AND ROADWAY COSTS OF A PROPOSED ELECTRIC INTERURBAN RAILWAY, BEING A SUMMARY OF CERTAIN ESSENTIAL ITEMS TAKEN FROM TABLE I WITH 5 PER CENT FOR ENGINEERING ADDED

	Cost per Mile of Track	
Accounts	Minimum	Maximum
1—Engineering and superintendence	$770	$1,560
2—Right of way	2,000	4,000
3—Other land used in electric railway operations	100	500
4—Grading	2,500	6,000
5—Ballast	1,500	4,500
6—Ties	1,820	2,600
7—Rails, rail fastenings and joints	3,700	4,200
8—Special work	400	600
9—Underground construction	....	....
10—Paving	....	....
11—Track laying and surfacing	800	1,200
12—Roadway tools	50	50
13—Tunnels	....	....
14—Elevated structures and foundations	....	....
15—Bridges, trestles and culverts	2,000	4,000
16—Crossings, fences, cattle guards and signs	500	1,000
17—Interlocking and other signal apparatus	....	2,500
	$16,140	$32,710

(Note: Track bonding is omitted because it is classified as a part of the distribution system.) From articles by L. E. Fischer, *Electric Railway Journal*, Sept. 6, 1913.

The construction costs for tracks on high-speed lines, elevated roads and subways are usually equal to the costs for first-class steam road tracks.

There is a great deal of money spent on track maintenance for which there is no improvement in permanent value. Tracks on private way are continually re-surfaced and re-aligned; rails and ties are renewed here and there and joints tightened up. In paved tracks, joint and rail repairs are more costly because of the incidental removal and restoration of the pavement. It is a well-known fact that pavement maintenance represents from 30 to 40 per cent of the total maintenance cost for tracks in paved streets. These details require careful consideration from an economic standpoint and it will often be found that large expenditures on radical improvements will result in great and continued economies in maintenance. There should be a constant effort to keep the condition of the track up to such a degree of

efficiency that a proper relation between the track condition and car traffic will be maintained since the deterioration of the tracks, if allowed to go too far, will have a marked influence on costs of car operation and maintenance of equipment.

The degree of track efficiency which is desirable is dependent to a large degree upon the general condition and age of all the trackage and the financial position of the road. It is obvious that a road of poor earning power can hardly afford the standard of maintenance expense which would obtain upon a road which has an ample income.

Track maintenance costs, like track construction costs, are subject to many factors which control the expenditures. As an indication of how the cost of maintenance may vary it may be stated that an examination [1] of the expense for maintenance of way and structures on ten interurban roads in 1913 indicated a range of from $800 to $1,000 per mile of track operated. This range compares closely with the costs covering the electric railways in the State of Connecticut in 1912, as found in the annual report of the Connecticut Public Utilities Commission. The cost of this item on urban roads will range from $1,000 to $2,000 per mile of track operated, being influenced greatly by the amount of reconstruction done in any one season, for the reason that the greater part of the cost of reconstruction work is really extraordinary maintenance and is charged to regular maintenance accounts. These figures are more interesting when it is stated that in 1913 it cost, on an average for all main tracks on steam roads, about $1,300 per year to maintain 1 mile.[2]

The maintenance expenditure for track and pavement on 100 miles of modern 7-in. girder rail track in Brooklyn, N. Y., having wood ties and grouted granite pavement on concrete and covering tracks from one to ten years old with an average age of nearly four years, was found to be $460 per mile per year.[3]

It was also found that the expense for joint maintenance represented 52.1 per cent, pavement 34.8 per cent, and corrugation 12.8 per cent of the total maintenance expenditure. Incidentally it was noted that about 26 per cent of the pavement expense was for repairs to pavement following joint repairs, and

1 L. E. Fischer, *Electric Railway Journal,* Sept. 6, 1913.
2 Willard: "Maintenance of Way and Structures."
3 See *Electric Railway Journal,* March 17, 1917.

also that 65 per cent of the total expense was confined to 11.4 per cent of the mileage, having been due mainly to a particular type of rail joint.

It will be apparent from the foregoing figures on maintenance costs that the engineer of maintenance of way needs to keep closely in touch with the expenditures of his department. Through careful analysis of expense and comparison with similar items on other roads as well as comparisons of different parts of his own road, he may search out the weak points and take steps to overcome them.

CHAPTER II

LABOR-SAVING METHODS IN THE WAY DEPARTMENT

The labor conditions created by the entry of the United States into the war have had a strong influence in directing attention of way departments to the possibilities for saving labor through the extended use of machinery. The use of machinery, up to a comparatively short time ago, was gradually increasing, but there was still a tendency to hold back expenditures for equipment. This was largely due to the fear that too much money might be tied up in equipment, a great deal of which is limited in scope and liable to be idle for long periods, especially in the winter season.

During the past two years, however, it has become evident that the main opportunity to overcome labor handicaps lay in the direction of labor-saving devices, and such machinery and tools now form a part of the way department equipment to an extent which would have excited wonder a few years ago. The way department yards have taken on an aspect resembling contractors' yards, and the general result has been that a much more businesslike procedure has taken its proper place in the scheme of things.

If there are any doubts as to the advisability of using labor-saving machinery to the fullest possible extent they should be dispelled by the results obtained from their use by the way department in track work in Elmira, N. Y., in 1917, as described by F. H. Hill in the *Journal* for June 30, 1917. Furthermore, John A. Beeler in his recent report on the Boston Elevated Railway, in commenting on the way department methods, says: "The methods employed are to be commended. Labor-saving devices have been introduced extensively and the amount of hand work has been reduced wherever possible. This has undoubtedly aided in keeping down maintenance costs. The use of such devices should be extended wherever possible, especially in view of the present shortage of labor."

With the advent of machinery, it has been necessary also to increase the supervision to some extent, because much of it requires a reasonable amount of attention and care if it is to be kept in a condition to give the best service, both in its application to the work and its performance as machinery.

General Tendency in Adoption of Equipment. The general trend of the interest in special tools and equipment has been toward the adoption of improved forms of work cars, such as crane cars and automatic dump cars; the increased use of the power shovel both for grading and for loading cars; the rapid adoption of pneumatic or electric tie-tamping tools; the broadened scope of the electric arc welders; the increased use of power drills in regular maintenance as well as construction work, and the general rearrangement of storage yards, including the installation of various forms of labor-saving devices therein.

Arc Welders Assume Importance in Effecting Economies. It is somewhat difficult to indicate just where the greatest savings have been effected or to indicate any particular tool or device which has been so signally successful as to excite exceptional comment. Yet there can be but little doubt that the use of the several forms of arc welders now available has contributed a very large share in effecting many economies in men and materials. These devices had their origin in the use of the acetylene flame as first presented to the industry under the name of the "autogenous welding process." Since it involved the use of rather expensive gases, and its range of use was somewhat limited, the process soon gave way to the arc welder, using the very convenient power from the overhead wire, until to-day there is no road of any size which is without some form of arc welding apparatus. With the use of the arc welder came a rapid development in its use in connection with the application of a simplified form of electrically-welded rail joint.

The early type of arc welder consisted of an arrangement of grid resistances which was effective but costly if the exorbitant use of power due to resistance losses was seriously considered. This has led to the development of dynamotor or motor-generator apparatus which has a greater range of use and is also highly efficient electrically, due principally to the absence of energy consuming resistance. With it all forms of joint welding, metallic electro welding, carbon arc metal cutting and electric bond

welding may be done, using only 10 per cent of the current required by resistor types of apparatus.

It has been found that with the arc welder the repair of defective rail joints can be done more quickly, with little or no disturbance to traffic and for about 10 per cent of the cost as compared with the method of cutting out the defective joint and installing an insert with two joints, with the incidental destruction and restoration of pavement and bonding.

Grinding Equipment a Necessity Even on New Rail. In connection with arc welders it is to be noted that their effective use, in track work at least, is limited to a certain extent by the accompanying grinding apparatus. The grinding equipment must be proportionate to the welding equipment if the full value of the work of the former is to be secured. Incidentally the grinding equipment investment can be minimized and the amount of grinding work done can be greatly increased if arrangements are made for rapid transportation of grinding apparatus by autotruck, so that one grinding machine may follow up from two to three welding gangs which may be widely separated.

Rail-grinding equipment is now a necessity where it was once considered a toy, and, aside from the grinding equipment long in use by the Lorain Steel Company in its joint work, the need for grinding apparatus was not generally recognized until rail corrugation began to be troublesome. Another factor which ultimately created a field for grinders was the rather late and sudden recognition of the fact that all rail joints, no matter what their kind, must be ground. There was also a period of experimentation in connection with conflicting views over the relative merits of the rotary and reciprocating principles. All of this delayed the general adoption of grinding apparatus until it was finally found that, while each type has its peculiar field of usefulness, good results can be had by the use of both types.

Types of Rail Grinders—Power Tampers No Longer an Experiment. Grinding apparatus may be classified into four general type groups, as follows: 1. Rail files (push files), hand operated, reciprocating. 2. Rotary grinders, flexible-shaft type. 3. Rotary grinders, machine-type, mounted on small trucks. 4. Reciprocating grinders, machine-type, mounted on small truck or special carriage.

The rail file, manually operated, served its purpose while labor was comparatively cheap and during the period of development of machines. Its chief use was for filing or grinding newly made joints. The flexible shaft rotary grinder came into use for the same purpose. It is now confined to grinding special track work where its peculiar construction has adapted it to this difficult field. It is a costly piece of apparatus to maintain, due to the abnormal failures of the shafting, and a new grinder has recently been developed for the same work which is far less expensive to maintain and less liable to cause injury to the workmen. This machine was illustrated in the *Electric Railway Journal* for May 26, 1917.

The larger machine types of rotary and reciprocating grinders and their uses are so generally familiar that they need not be described more fully. It suffices to say that both types are effective and efficient and that in general at least one machine of each type may be used advantageously on almost any property. In fact some classes of grinding work can be done best by the use of both, the one supplementing the other.

Incident to the use of grinding machines is the material composing the grinding wheels or blocks. All of this apparatus except the push files (which require a form of special steel bastard file) consume large stocks of abrasive material, and in consequence the selection of this stock needs careful attention, with the view to securing the most durable and effective material obtainable.

Tie tamping has been a bugbear with everyone who has had anything to do with track work. The time-honored custom of tamping by hand, with the tendency of the men to either "go to sleep" on each tie or else to skimp the work when pressed to wake up and cover ground, has at last given way to machinery. The mechanical tie-tamping devices now on the market came to the front just in time to be of great assistance at a time of extreme labor shortage. No longer an experiment, the pneumatic and electric tie tampers have become a part of the equipment of many way departments almost over night. The pneumatic type has had the greater development and is in more general use, but there are certain points in favor of the electric type which have great merit, principally the feature of availability of power, and if the electric machine can be made to overcome some pres-

ent disadvantage it may ultimately supplant the pneumatic apparatus.

The pneumatic tampers have produced savings that are remarkable. Tamping can be done mechanically for half the cost of manual tamping. The proportionate saving in men, however, is even greater, and this is a particular advantage, as the much smaller force required is also of a higher grade. The number of men required for mechanical tamping is only 30 per cent of the number required for hand tamping. In addition the tamping itself is far superior to the best hand labor.

Power Drilling Machines Save 75 Per Cent Over Hand Drilling. Rail drilling is another field where mechanical means have been resorted to with beneficial results in labor saving. That old-time standby, the ratchet drill, has been displaced almost entirely by the electric power drill, except for emergency use and for certain classes of repair work. It has been found that the power drill will cut the cost of track work in its sphere at least 75 per cent over hand methods. By cutting down the number engaged on drilling the power drill has also released a large number of men for other work. Incidentally there is a saving in drill bits and cost of sharpening due to the uniformity of working conditions created by the use of the power machine. In hand work with ratchets there is apt to be distortion in position of bits and other parts created by careless handling which lead to rapid breakage of bits.

In connection with power drilling it should be noted that there is a new type of power-operated ratchet drilling device which is available for use wherever pneumatic tools are used in track work. This device has the compactness of the hand-operated ratchet and is available for use in cramped space at joint repairs when the electric drilling devices cannot be used without destruction of a considerable area of pavement to make room in which the apparatus can work.

Regardless of the nature of the drilling device, the drill bits receive very rough treatment, and the high carbon steel rails in general use are particularly difficult to drill even with the highest grade of special tool-steel drill bits. At this point the special tool-grinding machinery of the portable type comes into service. By means of special tool holders, any type of bit can be resharpened by the average laborer and the bits will do better work

than if sharpened by the average machinist at a shop. There is no lost time waiting for fresh bits and a smaller stock can be carried, which is an item of moment when the present very high cost of drill bits is considered. Special tool-sharpening devices of this character are now considered indispensable on jobs where more than a few holes are to be drilled, and they should be in every gang tool box.

Power Shovels for 50 Per Cent Economy. The electric shovel has also come into quite a general use as a labor-saving device, and consideration should be given to its use at every point where the controlling conditions will permit. It is invaluable when it can be employed for breaking up concrete, in excavating and grading on extension work, and in reconstruction work where the street widths will permit. In the latter situation it can best be used when there is room for the installation of a temporary third track. These shovels have been known to save their cost in doing two miles of track work. Under favorable circumstances they will reduce the cost of excavating by 66⅔ per cent, and cut the cost of teams 50 per cent, which latter is a very great advantage at this time, when teams are not only high in cost but also difficult to get at any price.

The Pavement Plow as a Man Saver—Specialized Work Cars Beat Junk. Another labor and time-saving device is the pavement plow, the use of which has greatly extended in the past two years. As an aid in the removal of block pavements of all types and with all kinds of paving joint fillers it has proven its worth as a labor saver. This device will do as much work of the most difficult kind, in an hour or less, as five men can do in three nine-hour days and for less than 25 per cent of the manual labor cost. The need for men is so great that the saving in man-energy alone would make the device worth while even if the costs were the same.

An active interest has been created in the improvement of work cars for handling materials and the shortage of men has done more than anything else to direct attention toward the need for reduction in men used in this branch of the work. Until recently most bulky material, such as paving blocks, sand, gravel and crushed stone, were handled by men, who loaded the material onto ordinary flat cars at the yards and unloaded it again at the job. Sometimes the men were transported with the

load, where there were none available at the point of unloading. From eight to ten men are usually required for this sort of work.

There was a time, not long ago, when any old collection of junk on wheels was considered good enough for a work car. In that day the way engineer who asked for specially designed work-car equipment was apt to be considered somewhat crazy. The development of the automatic side-dumping car has changed all this, much to the advantage of the companies. It is now possible to unload a 3-car train of automatic dump cars with one man, where six or eight were formerly required by such cars. The whole trainload can be dumped in from 3 to 5 min. where it formerly required about 20 to 30 minutes per car. Such equipment has further advantages in the saving of time of the equipment on the road, in lessening of tie-up of passenger car traffic while unloading between cars under regular service conditions, and in availability for use in general revenue freight service in hauling material for highway contractors as well as in the railway coal service.

It has been authoritatively stated that automatic dump-car equipment has saved as much as 30 cents per foot in the cost of track work in a large city in the Central West. The locomotive crane and the pillar crane, mounted upon cars, have taken an important place in the list of labor-saving equipment. When especially designed for electric railway work they are of particular value in handling special-work installations, in loading and unloading rails upon the street, and in the general work of handling materials. As an indication of the savings which may be accomplished through use of derrick cars the table below is reprinted from the *Electric Railway Journal* for Dec. 23, 1916:

SAVING EFFECTED IN FOUR YEARS BY USE OF 3-TON PILLAR CRANE CAR ON ELECTRIC RAILWAY SYSTEM

	Cost of Handling		
	Without Crane	With Crane	Total Saving
4000 tons miscellaneous	$1.00	$0.25	$3,000.00
3324 tons load on cars	.75	.20	1,828.20
3324 tons to yard	1.00	.25	2,493.00
6340 tons unloaded	.50	.20	1,902.00
6340 tons to job	.75	.25	3,170.00
			$12,393.20

Cost of crane car, ready to run	$7,000	
Depreciation 5 per cent, four years	1,400	
Interest 5 per cent, four years	1,400	
Upkeep 2½ per cent, four years	700	
		$3,500.00
Net saving four years, one car		$8,893.20

In connection with the subject of dumping cars it may be well to call attention to a phase of the work of handling materials where there is room for the development of mechanical means which will save a great deal of labor. We have reference to the need for some form of power loading device which can be used in the confined areas of narrow city streets, alongside track trenches, for the purpose of placing the excavated materials upon the cars, thus lessening the amount of manual labor which is still employed for this purpose. Both grab buckets with cranes and electric shovels may be used to a limited extent in this way, but street conditions more often prevent this.

The subject is being studied in several quarters and there is no doubt that once the attention of manufacturers of several types of automatic loading devices now used extensively in coal yards for loading coal from the piles into wagons is called into active consideration of the field waiting for development we may expect to see a satisfactory solution of the problem.

Air Drills and Skull-Crackers for Concrete. In removing old track prior to reconstruction it is often necessary to remove a concrete paving base. Several methods have been adopted recently to do this work mechanically in order to replace the old method of digging jack holes, raising the track and breaking down the concrete with heavy mauls. This method is tedious, requires a great many men and is liable to cause serious disturbance to adjacent concrete under roadway pavement which is to be left in place. Such disturbances lead to excess cost of concrete for the new track because of the necessity for breaking out and replacing shattered concrete.

In this field there have been two developments, each of which is effective in saving of labor. One is the use of air drills in connection with compressor apparatus available for operation of tie tampers. With four air drills a gang of six men can remove as much of the hardest kind of track concrete in a day as a gang

of fifteen men can accomplish manually, using heavy bull punches, jacks and mauls.

Another method is to utilize the so-called "skull cracker," which is a heavy casting weighing about a ton, attached to simple derrick, moving on the track and so rigged with a release trigger as to drop the casting from a height of about 12 ft. onto the concrete. It has been reported that this comparatively simple device has effected a saving of from 15 to 20 cents per foot of single track in labor cost of this work. The "skull cracker" is moderate in first cost and is available in many cases where there is no air equipment suitable for operating air drills.

Concrete Mixing Machinery Will Save Its Cost Many Times Over. There has been a rapid development in the application of machinery to mixing concrete and cement grout for track pavement work. This has been assisted, particularly in the case of mixers, by the change in opinion as to the practicability of machine mixing compared with hand mixing. There are at least two mechanical grout mixers now on the market which are acceptable to highway engineers. In fact, one of these had the advantage of being developed by its manufacturer under the direction of a board of experienced highway engineers with gratifying results. It is now possible with the mechanical mixer not only to save materials and secure a high uniformity of mixture, but also to save from 3 to 5 cents (42 to 70 per cent) per square yard in the labor cost of mixing. In addition a mechanical grout mixer will follow up and complete the grouting of all the pavement which can be laid in a track job in any one day under ordinary conditions. The advantages in completing the grouting so quickly are apparent.

In the concrete-mixing field the development has branched in three directions: (1) In the increasing use of the moderate-sized batch mixer; (2) in the adoption of very large-sized batch mixers with self-loading hoppers, mounted upon trucks and self-propelling, generally upon the track and sometimes on the roadway surface alongside, and (3) in the assembling of complete and rather complicated mixing plants upon a train of two or more cars.

Each of these methods has its field and has proved very successful. For all round use, particularly because of its mobility, the small batch mixer operated by a gasolene engine may be

considered the most serviceable, especially in view of the fact that the cost of this machine is very moderate.

The larger, self-propelled mixers are more for use on very large jobs where a large volume of concrete must be produced rapidly. It has been observed that one, or at the most two, of these machines will serve very extensive reconstruction programs on systems of the greatest size, and the output of such machines by the mixer manufacturers for railway customers has so far been somewhat limited. To some extent this restriction may be due to the prevailing custom on many systems of letting the track-paving work out to contractors who usually have the paving work for the city. This is often being done in conjunction with the railroad track work.

The special concrete mixing plant mounted on trains of cars has been used in but few instances and interest in this type of plant has been revived by the action of the Denver Tramway Company in selecting it for that property, as described in the *Electric Railway Journal* for Oct. 6, 1917. The particular advantage claimed for this equipment is in the elimination of the storage of any concreting materials on the street. This does away with a large amount of labor required for handling, obviates complaints from property owners fronting the work and tends to preserve the cement from theft and from damage by the elements.

From the foregoing it will be observed that the railways are alive to the fact that concrete mixing machinery, when properly selected, will save its cost many times over, and there is no reason why every property should not take advantage of some one of the several types of apparatus which are available.

Kerosene Torches and Asphalt Surface Heaters. During the winter season there is a great amount of labor expended in keeping switches, switch-operating mechanisms and interlocking free of snow and ice. In this work the kerosene torch has come into use and it has been found that one man equipped with such a torch will displace from three to five men and do better work. These torches have other uses which make them serviceable the year round. They are indispensable in connection with the work of resetting hard-center plates in special track work.

Where there is a considerable amount of asphalt pavement in tracks the asphalt surface heater or burner is effecting large

economies in men and materials. It consists of a set of five or more burners using kerosene and arranged on a carriage which also has a sheet-iron hood, about 4 or 5 ft. square, over the burners. The burners and hood are very close to the pavement surface, so that the heat is concentrated and the flames are protected from the wind. These heaters are used to soften the asphalt surface where it is desired to fill up worn areas which have not exposed the concrete. By their use the cutting out of much good surface material is avoided, as it is only necessary to add more material on top of the old material, after sufficient heating, and to finish the surface by rolling or tamping. Specially shaped hoods and heaters have been devised for use in repairing narrow ruts in asphalt along the rails, and by their use a saving of 50 cents per square yard of pavement surface has been effected.

These heaters have also been used to great advantage in heating cobble and block pavement in extreme cold weather preparatory to its removal for emergency track repairs, and have made possible the making of repairs in three or four hours' time which would have otherwise consumed a day.

Methods of Cutting Asphalt Surface. It is often necessary to remove sheet asphalt entire for new track construction or for reconstruction. There have been at least three recent improvements in methods of doing this work which have been described in these columns. Each of them does away with the onerous and expensive method of cutting manually with the asphalt mattox. One method involves the use of a special cutting tool designed to operate with the air-operated tie tamping machine, as described in the *Journal* for June 30, 1917. Another utilizes an ingenious arrangement of a cutting wheel mounted in outrigger fashion upon a work car (see *Electric Railway Journal* for Jan. 20, 1916).

Still another plan involves the use of a tee-iron with a cutting edge laid upon the surface and made to cut by operating a small road roller over it. (See *Electric Railway Journal* for July 7, 1917.) Again, the work has been accomplished by mounting special cutting edges completely around the circumference of the rear roller of a small tandem road roller and running the roller over the area to be cut.

Each scheme has a good deal of merit, and any one of them

will be found clearly in the labor-saving class. For instance, the air-operated cutting device is reported as having worked at the rate of 47 feet per hour. It would take one laborer several hours to do the same work manually.

The oxy-acetylene cutting flame or torch has proved to be effective as a time and labor-saving device. It is now used extensively in the work of removing old rails, replacing the chisel and sledge in cutting bolts at joints and replacing hack saws for cutting rails into short lengths prior to loading on cars. It is also of great service for cutting the ends of frog arms and other special work made of manganese steel, which is almost impossible to cut by any other method. There are many other uses to which this tool may be put, and these illustrations serve to call attention to a piece of apparatus which is almost indispensable as a part of the labor-saving equipment of the way department.

There has been a great deal of interest during the past year in connection with the possibilities for labor saving which are presented in the storage yard of the way department. Until a short time ago most yards consisted of a lot of nondescript tracks with partly worn-out rail and special work and a number of cheaply constructed gin poles or stiff-leg derricks scattered about largely at random, and with comparatively few installations of modern types of traveling cranes, derricks and other equipment of adequate design. This was perhaps the result of spasmodic growth from small beginnings, which prevented the consideration of the subject from an economical viewpoint. A great many yards have not been located to the best advantage with respect to the radius or center of distribution in combination with the sources of original supply.

The labor shortage has led to a renewed consideration of the whole subject, and a number of articles bearing on the matter were published in this paper in the early part of 1917 which brought out a good deal in the description of the important yard improvements made at Cleveland and at Denver, where two quite distinct methods of handling materials and types of yard layouts were compared. The Cleveland installation was described in the *Journal* for Feb. 24, 1917, while the Denver plant was the subject of an article in the issue for Oct. 27, 1917.

These two articles in particular served to emphasize the im-

portance which the storage yard itself, its location and its handling problem have assumed. At the same time they presented definite facts which indicated the large saving in labor which must always result from a concerted effort to improve conditions in this quarter.

This is well illustrated by the statement made in the Denver article, in which it is stated that with the new yard layout three men can handle as much material as fifteen could handle in the old yard. At Cleveland one item of unloading a car of granite, for instance, showed a 25 per cent reduction in labor cost.

While it is quite clear that no one best way will be found to handle materials most economically on all properties there is no doubt but that the locomotive crane has been found to be one of the most useful pieces of apparatus for this sort of work, suitable alike to large and small yards and having other uses out on the road which make it a profitable investment.

CHAPTER III

HOW WAY ENGINEERS RATE LABOR-SAVING APPLIANCES FOR USE IN TRACK WORK

In order to permit the compilation of the experience of way engineers on the subject of track tools and other appliances, the editors of the *Electric Railway Journal* asked a number of them to telegraph or write briefly their answers to the following questions:

1. What piece of special machinery or special tool has been the greatest labor saver on your property or properties in way department work?

2. What is the order of merit as labor savers of the following tools or devices: Arc welder, power drill, electric shovel, air tamper, concrete mixer, crane car, automatic dump car, pavement plow, concrete breaker, stone crusher, acetylene cutting flame?

Telegrams and letters were received from a number of companies and these are summarized as follows:

From J. M. Larned, engineer maintenance of way, Pittsburgh (Pa.) Railways:

In regard to the relative importance of different pieces of track equipment, I would arrange them as follows: Question 1—Crane car. Question 2—Arrange in this order: crane car, electric shovel, air tamper, concrete mixer, stone crusher, dump car, arc welder, rail grinder, ballast spreader, track drill, acetylene torch.

From A. E. Harvey, engineer maintenance of way, Kansas City (Mo.) Railways:

All things considered I believe that our crane car has saved us more in labor than any other one piece of equipment, but I believe that there are several other kinds of equipment that are just as necessary to the accomplishment of the work in an economical manner. As to the second question I do not believe that a fair comparison can be made as to the relative economic value of the devices mentioned, as each is suited to its particular kind of work. Where such work predominates the machine that is fitted for it takes precedence in an economic sense over all other equipment. All of the devices are such great labor savers

that where there is any considerable quantity of work to be done to which they are adapted they are just as essential to the proper handling and economical conduct of the work as are the most common hand tools. They should, therefore, not be considered as special tools but just as necessary a part of the outfit as a pick or shovel.

From W. R. Dunham, Jr., engineer maintenance of way, Connecticut Company, New Haven, Conn.:

The crane car has been the greatest labor saver on this property. In order of importance the devices listed in the second question might be arranged as follows: Crane car, arc welder, air tamper, power drill, electric shovel.

From H. M. Steward, chief engineer Boston (Mass.) Elevated Railway:

In answer to your request would state that the arc welding outfit seems to be the most useful apparatus. I should arrange in the following order the list given in question 2: Arc welder, crane car, power drill, air tamper, automatic dump car, electric shovel, concrete mixer, pavement plow, concrete breaker, acetylene cutting flame.

From J. P. Ripley, railway engineer J. G. White Management Corporation:

Taking all in all it is my opinion that the electric welding machine has been the greatest labor saver in the track department. It saves materials as well as labor. Instead of renewing a frog, for instance, the points can be rebuilt by welding. Your second question is difficult for us to answer because conditions vary on our different properties. We think the welding machine comes first and a concrete mixer is considered generally a necessity and might come second, and the same is true of the power drill.

We have not as yet given the pavement plow a trial and usually purchase stone already crushed for ballast. We have not tried the electric shovel or the air tamper but believe the latter at least has great possibilities.

From E. A. West, chief engineer Denver (Col.) Tramway:

Answering question 1, I should put arc welders first. I should arrange the equipment in question 2 in the following manner: Arc welder, acetylene cutting flame, air tamper, crane car, concrete mixer, portable stone crusher.

From Ford, Bacon & Davis, New York City, for several properties operated:

Ithaca (N. Y.) Traction Corporation—The rotary sweeper for removing snow has been the greatest labor saver.

Central New York Southern Railroad, Ithaca, N. Y.—The acetylene welding torch is the most useful device.

Lackawanna & Wyoming Valley Railroad—This company operates under steam road conditions and as the questions pertain almost exclusively to street work no answers of value can be given. The company understands, however, that the air-tamping devices are being used on steam roads with good results.

Empire State Railroad Corporation—The acetylene cutting flame is considered by this company to be the most efficient of all the labor-saving devices listed.

United Railroads of San Francisco—The crane car has been the greatest labor saver in our way department. We would arrange the list in question 2 as follows: Crane car, air tamper, automatic dump car, pavement plow, electric shovel, power drill, arc welder, concrete breaker, acetylene cutter, portable stone crusher. We are now ordering a concrete mixer which we hope to rank about fourth in the above list.

From C. G. Keen, engineer way and structure, American Railways Company, Philadelphia, Pa.:

As you know I am not in close enough touch with actual operating conditions to reply in respect to the labor-saving features of the tools mentioned. In respect to their values in maintenance work, however, I would place the arc welder in connection with the grinding machine easily first in importance.

From F. H. Hill, general manager Elmira Water, Light & Railroad Company, Elmira, N. Y.:

Replying to your inquiry I should place the pneumatic tie tamper at head of the list as the greatest labor saver in construction work. As to the list in your second question I should arrange the order as follows: The air tamper, arc welder and acetylene cutting flame are all indispensable. Power shovel and concrete mixer are necessities on construction work of any appreciable size. We do not have the other devices listed. A rail grinder in connection with a welder certainly prolongs life of track and equipment.

From Charles H. Clark, engineer maintenance of way, Cleveland (Ohio) Railway:

On this property we are agreed that the pavement plow is the greatest labor-saving device that we have. It not only saves a large amount of labor but accelerates the work. To arrange the tools in your second question in order of merit is a rather hard proposition, for some tools are dependent upon others for their efficiency. However, this order

may be suggestive: Pavement plow, crane, automatic dump car, concrete breaker, concrete mixer, acetylene cutting frame, electric shovel, power drill, air tamper, arc welder, stone crusher. An explanation is due in connection with this list. All of the devices are labor savers. A stone crusher is not necessarily a labor-saving device, it might more properly be called an economical machine. One might not need an acetylene torch but it will cut rails faster than twenty men can do. An electric shovel might be a poor adjunct unless there were sufficient work for it. We find use for two shovels. The arc welder is a necessity.

Summary. The answers to question 1 indicate that, as far as this questionnaire is concerned, the crane car leads and the arc welding apparatus is a close second. The acetylene torch comes next, and there is honorable mention for the pavement plow and the pneumatic tamper.

A summary of the answers to question 2, weighing each in accordance with the number of votes, gives the following as the order of preference: 1—crane car; 2—air tamper; 3—arc welder; 4—automatic dump car; 5—concrete mixer; 6—pavement plow; 7—electric shovel; 8—power drill; 9—acetylene torch; 10—rail grinder; 11—stone crusher; 12—ballast spreader.

It would be unscientific to conclude that this list is at all conclusive—first, because only a few excellent devices were listed; second, because the canvass was only partial. The list, however, is suggestive, and will be useful in directing attention to the fact that way engineers appreciate the value of tools.

CHAPTER IV

SELECTING AND CARING FOR HAND TOOLS USED BY WAY DEPARTMENT

The constant effort which is being made to effect economies in track maintenance work has caused a searching inquiry to be made into many divisions of the work which in normal times have been subjected to rather superficial and desultory consideration. The subject of small hand tools used by the way department may be placed in this class.

Poor Tools Cause Waste of High-Priced Labor. Ordinarily one would not think it worth while to pay much attention to such matters as tool sharpening, control of supply of tools, overstocking, extra handling and cost of tool supply service. We have all known in a general way that we are using a great many hacksaw blades, or that our picks seem constantly to be on the way to or from the blacksmith shop, but we have not been required to economize because of a lack of an adequate supply of new tools at reasonable prices. Wartime prices for tools and supplies have put these articles upon a higher plane and we are beginning to realize how essential they are. It is brought home to us that we cannot do without the pick and shovel, or the lining bar and spiking maul any more than we can dispense with the men who use them. Consequently the fact becomes evident that it is the very antithesis of economy to pay high prices for labor and then equip it with poor tools. On the contrary, the tools and their condition should receive expert attention with the object of seeing that they are in every way fit to assist in getting full value from the laborers who use them. This point is emphasized by statistics which indicate that more than 60 per cent of the cost of track or maintenance work is spent in payrolls, for labor, and nearly all the time is spent in using tools.

There are also numerous small supplies which are in common use, the consumption of which during a year's work is astonishingly large in quantity. A casual examination of the list of

such small things as sandpaper, emery cloth, hacksaw blades, folding rules, lantern and lantern globes, kerosene oil and red flags, which have been used by the average track department in a season, will be an eye-opener to anyone who has not paid much attention to details in this regard.

Before considering either tools or supplies further it will be of interest to inquire into the practice as to the issuing of tools and accounting therefor. In the first place, there should be uniformity in practice and the entire procedure should be carefully outlined. Comparatively simple record systems should be used which will cover the progress of all tools and supplies from the storeroom to the tool box, and thence by monthly checking of the latter until the tools are returned for sharpening or replacement due to loss or breakage and until supplies are exhausted.

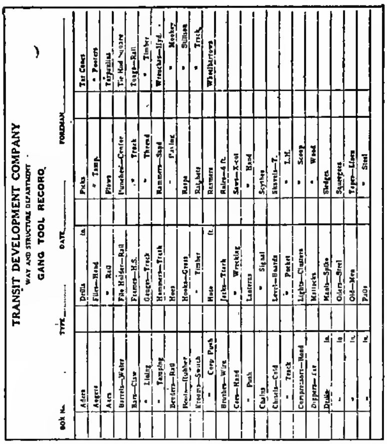
Each foreman should be made responsible for the economical use of tools and supplies and for all loss, breakage and misuse. Any extraordinary consumption of tools or supplies, or reported breakage of certain tools, should receive prompt attention with the view of determining whether the consumption may be due not to wear or extra work but to theft or misuse. Continued breakages may mean poor quality of material. Extra large returns of tools for sharpening, particularly from a gang confined to one class of work where use to which tools are put is uniform, should be a cause for study as to whether the blacksmith work is being done poorly.

Each foreman should be required to report once a month on the contents of his tool box. The report should be on a printed form of the simplest character upon which are listed all the standard tools, with space for the few odd, little-used tools which are occasionally supplied. Such a form of tool report is shown in Fig. 1-A.

On large city systems it has been found advisable to employ a tool foreman, one of whose duties is to check up the contents of tool boxes at least once a month. When such a man is employed the form of tool record shown in Fig. 1-B has been found useful. In addition to this form the one shown in Fig. 1-D is used to make a record of delivery for tools and supplies which are handled and consumed in large quantities during each month of a busy season. A similar form is used to make a record of tools picked up by tool cars. These forms serve to protect the foreman and

the motormen and chauffeurs who make the deliveries and collections.

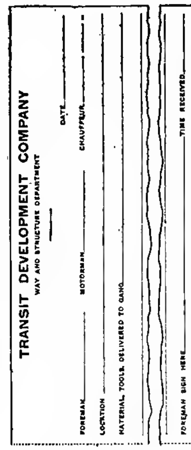
A Simple Order System Prevents Loss of Tools. It is not generally good practice to permit foremen to order tools directly, except in case of emergency. They should make their wants



TRANSIT DEVELOPMENT COMPANY
WAY AND STRUCTURE DEPARTMENT
GANG TOOL RECORD

BOX No. TYPE DATE FOREMAN

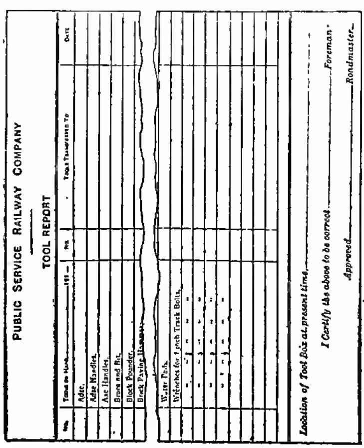
B—A Convenient Form for Recording the Tools in Use by Different Gangs



TRANSIT DEVELOPMENT COMPANY
WAY AND STRUCTURE DEPARTMENT

DATE
FOREMAN MOTORMAN CHAUFFEUR
LOCATION
MATERIAL, TOOLS DELIVERED TO GANG
FOREMAN SIGN HERE TIME RECEIVED

D—Delivery of Tools and Supplies Can Be Effectively Recorded by Means of This Form

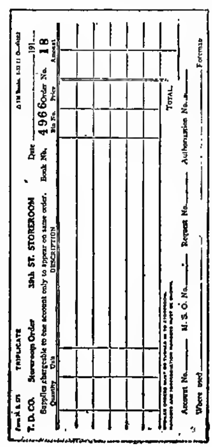


PUBLIC SERVICE RAILWAY COMPANY
TOOL REPORT

Adze. Adze Handles. Axe Handles. Brace and Bit. Block Pounder. Water Pails. Wrenches for 1 inch Track Bolts.

Location of Tool Box at present time
I Certify the above to be correct. Foreman
Approved Roadmaster

A—This Form Is Useful in Reporting Contents of Tool Boxes and Provides a Record of Any Tool Transfers Made



T. D. CO. TRIPLICATE Storeroom Order 39th ST. STOREROOM
Book No. 4966 Order No. 18
Quantity Unit DESCRIPTION Price Amount
TOTAL
Account No. M. S. O. No. Request No. Authorization No.
Where used Foreman

C—This Form Is Used for Drawing Supplies from the Storeroom and Prevents Use by Unauthorized Persons

FIG. 1—GROUP OF RECORD FORMS FOUND USEFUL IN THE WAY DEPARTMENT

known to the roadmaster or supervisor, and no tools should be given out except on proper storeroom order signed by persons authorized to sign orders. A form of storeroom order used for this purpose is shown in Fig. 1-C. When foremen sign they are usually shop foremen authorized to do so. Also, some roads make a rule that no new tool shall be given out unless an old

tool of like character be returned. This simple rule makes it necessary to account for losses where the old tool is not available for return and tends to create more careful use and to insure return of tools to the tool box at night.

The tool foreman occupies a position of considerable importance. Besides his duty in checking up tool boxes he generally handles the tool requisitions and secures the tools and supplies from the storeroom, sending them out to the various groups either by the regular tool-car service or by auto truck. The proper routing of a tool supply car or truck is no mean task. He also keeps a watch on the tool and supply stock in the storeroom, keeping his superior advised of conditions of stock so that it may be replenished in time to prevent delays to the work.

On moderate sized roads and those having widely separated divisions, the roadmaster generally performs many of the duties of the tool man, acting in direct conjunction with the storekeeper. In such cases tools are usually sent to the job and picked up by regular work cars when making other deliveries.

It is almost imperative that all tools be marked by stamping or branding with some form of distinguishing mark such as the name of the company and the department. Such markings should be done in a manner which will render their removal as difficult as possible, as they serve to prevent theft and interchange with tools of contractors who may have gangs working near truck gangs. For instance, the marking of shovels is of particular importance in some cities where the contractors' custom still prevails of requiring the laborer to provide his own shovel.

The number of different tools used in track work alone is quite large, as will be seen from a glance at those listed for an ordinary tool box in Fig. 1-B. This list contains eighty different items. Besides special tools not listed there are also the several special tools used by pavers, bonders, special-work repair men, blacksmiths, grinder men and bridge men.

There are at least eighteen distinct tools in regular use by a blacksmith, not including his anvil, forge, water keg and several types of tongs for handling the hot metal. The blacksmith, by the way, is a very important individual in any track organization, not only because of his work in joint repair and prepara-

tion of compromise joints in the field but also because of his usefulness in the repair of tools.

The work of special-work repairmen calls for several special tools, particularly chipping tools for use in resetting hard centers. These are shown in Fig. 2. In addition to these the hard-center gang uses a special torch for heating babbitt or spelter to permit removal of centers, and another for heating these metals preparatory to pouring them around the centers.

Lists of the general run of track tools are given in the gang tool records shown in Fig. 1-B. Each gang should have a complete outfit of standard tools in sufficient number to supply every man in the gang. Extra tools and parts are also required to take the places of those which break or which must be sent to the shop for repair. Where the gangs are in cities, close to sources of supply, but a few extra tools need be carried, as those needing replacement can usually be exchanged quite readily. The section gang which is liable to be a long way from supplies naturally needs to have some extra tools to fill in until replacements can be made.

The equipment of gangs will vary considerably, depending upon the size of the gang, upon the general nature of the work, and upon whether the gang is a section gang employed upon T-rail only or whether it may be employed on girder rail in paved streets.

Special Tools Need Special Handling. The list of tools given in Table I is indicative of the average equipment for city gangs of (1) sixty men on construction work; (2) of ten men on repair work; (3) of sixteen to eighteen men on special work; and (4) of six men on section work on T-rail track. The list covers certain conditions and will be varied by roadmasters more or less in accord with local practice. For instance, roads having several divisions will be found to have at least one electric track drill as a part of each roadmaster's tool equipment. On the other hand, some large city systems prefer to control these machines from headquarters, sending them from gang to gang as occasion warrants, usually by auto trucks. Again, snow shovels are kept at headquarters and distributed only in the winter season. Even then but few gangs carry more than a half-dozen or so because it is necessary to provide hundreds of them during big snowstorms when gangs are rapidly increased for such emergencies

TABLE I. STANDARD LIST OF TOOLS FOR TRACK MAINTENANCE GANGS OF SEVERAL SIZES

Tools	Construction Gang 60 Men	Repair Gang 10 Men	Special Work Gang 16 to 18 Men	Section Gang 6 Men
Adzes	2	1	2	2
Axes	1	1	1	1
Bars—Claw	5	2	6	3
Bars—Lining	20	8	12	4
Bars—Tamping	20	4	12	4
Benders—Rail (furnish as needed)	..	..	..	..
Boots (furnish as needed)	..	..	..	..
Brooms—Switch	4	1	4	3
Brooms—Corporation Push	3	2	2	2
Brushes—Wire	2	1	1	.
Cars—Hand			..	1
Cars—Push	1			
Chains	2	..	2	..
Chisels—Cold	2	..	..	
Chisels—Track	20	8	20	2
Chisels—Asphalt	6	2	2	
Compressors—Bond	1	1	1	1
Dippers—Water	2	1	1	1
Drills—$\frac{7}{8}$ in. (minimum number)	4	4	5	4
Drills—$\frac{15}{16}$ in. minimum number)	4	4	5	2
Drills—1 in. (minimum number)	4	4	5	2
Drills—$1\frac{1}{8}$ in. (minimum number)	4	4	5	2
Drift pins	4	4	3	..
Files—Hand—Round	1	1	..	
Files—Hand—Flat	1		..	3
Files—Hand—Rail	1	1	1	..
File holder—Rail	1	1	1	..
Flags (furnish as needed)		..	..	..
Frames—Hacksaw (at least 1 doz. blades to each frame)	4	4	6	2
Gages—Track	2	1	3	3
Gages—Wood (insulated)		..	..	1
Grinder — Keystone tool	1	1	1	1
Hoes	4	1	2	.
Hooks—Grass	..	..	..	2
Hose—Rubber	100 ft.	15 ft.	30 ft.	
Hydrant connection	1	.		..
Jack—Track	6	2	5	3
Jack—Wrecking	2	..		..
Jim Crows	..	..	1	1
Lanterns	50	12	35	15
Lanterns—Signal	..	..		3
Level—Boards	2	1	2	1
Level—Pocket	2	1	2	..
Light clusters		..	..	..
Mattocks	1	..	2	1
Mauls—Spike	8	4	8	4
Oilers—Steel	1	..	1	
Old men	2	3	2	2
Pails	6	2	4	3
Picks	20	8	16	10
Picks—Tamp		..	..	4
Pipe—Water	250 ft.	..	..	..
Plows	..	..	..	..
Punches—Center	2	1	1	2
Punches—Track	.	..	5	..
Punches—Thread	2	2	..	..
Rammers—Sand	6	2	4	..
Rammers—Paving	1	1	..	..
Rasps		..	3	..
Ratchets	4	3	6	2
Reamers	2	2	8	..
Rules—6 ft., folding	1	1	1	1
Saws—Crosscut	1	..	2	1
Saws—Hand	1	1	1	1
Scythes	..	..	..	2
Shovels—Track sq. pt.	20	6	10	12
Shovels—L-H	..	..	..	4
Shovels—Scoop	8	..	..	4
Shovels—Wood	..	..	..	2
Sledges	10	3	10	1
Spike pullers	..	..	2	1
Tongs—Rail	12	4	10	8
Tongs—Tie	..	..	.	4
Tapes—Linen	..	..	1	1
Tapes—Steel	1	1	1	1
Tarpaulins	1	..	1	
Tie Rod—Square	1	1	..	1
Wrenches—Hydrant	1	1	1	.
Wreoches—Monkey	1	..	1	1
Wrenches—Stillson	1	..	..	
Wrenches—Compressor	1	1	1	1
Wrenches—Track	10	4	12	6
Wrenches—Tie Rod	4	1	4	1
Wheelbarrows	6	3	6	2
Water barrels	..	1	2	..

and large numbers of shovels can best be stored and distributed from headquarters.

It is not the custom to provide all gangs with rail benders or jim crows. These are usually kept at headquarters and sent out, as needed, by the roadmaster. Exception is made at times to this rule for particular special-work gangs and section gangs which have to cover a large yard of T-rail track. Where a section gang has rock cuts on its portion of the line, slides are liable to occur. Such a gang must have rock drills, striking hammers, powder and fuse for emergency use.

Small Tool Standardization Has Several Advantages. The importance of having all gangs equipped with one style of each tool is worth noting. This is particularly advantageous because it allays any petty jealousies which may develop between gangs through real or fancied superiority of one style of the same tool (jacks, for instance) over another. Furthermore, if gangs are doubled up in emergencies there will be less tendency for borrowing the other fellow's good tools and returning poorer tools in their places.

It is very desirable to have standard plans of all tools. These plans will be found of great value in purchasing and inspecting them. If the making of such plans appears burdensome or unnecessary it is still possible and worth while to select them by number or description from the catalogs of the reliable supply houses and always to order the same makes and styles of those tools known to be most efficient. Standard plans of tools have another use in furnishing details for the repair and local manufacture of tools such as level boards and track gages. The standard tool plan shown in Fig. 3 is made up upon a sheet 4 in. x 6 in. with a 1-in. margin at one end for binding in loose-leaf book form. A drawing of another track tool appears in Fig. 5.

Specifications for Tool Steel Are Important. In the selection of tools made of steel, more attention should be paid to the quality of the steel and its suitability for the work. The steam roads have given more study to this than the electric roads. For instance, the Pennsylvania Railroad has its picks made of open-hearth steel having from 0.55 to 0.75 per cent carbon, not more than 0.04 per cent each of phosphor and sulphur, and about 0.40 per cent manganese. Similarly its track chisels

and track punches are made of crucible steel having from 0.80 to 0.90 per cent carbon, not more than 0.04 per cent each of phosphor and sulphur and 0.30 to 0.40 per cent manganese.

The further advantage of study of the proper quality of steel for track-tool use is illustrated by the experience of one electric railway which found in 1915 that it could substitute "Black Diamond" crucible steel at 7½ cents per pound for Jessup tool steel at 16 cents per pound and secure equally good results from tools, such as pick points, track chisels and punches, made therefrom. The saving thus effected amounted to a considerable sum in the course of a year.

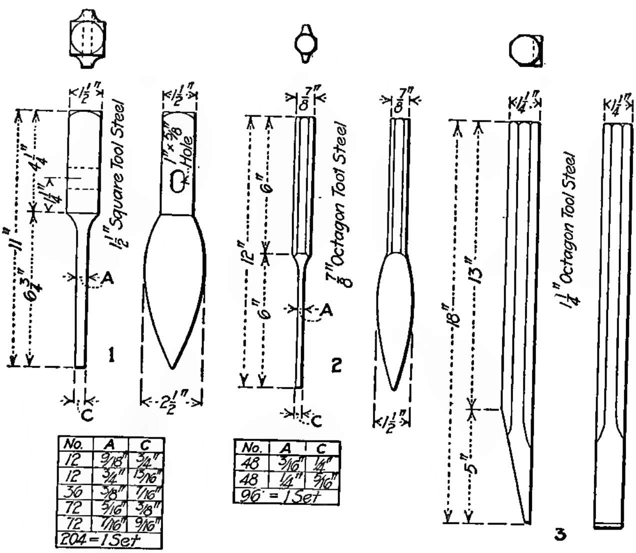


FIG. 2—THESE CHIPPING TOOLS ARE USED IN RESETTING HARD CENTERS

The Shovel Question Will Bear Investigation. Again, the quality of steel in track shovels will bear attention, especially where the men are required to furnish their own shovels, although this practice is considered poor policy. The usual effective depth of a shovel blade is about 10 in. An inch of wear reduces its capacity nearly 10 per cent. Men have been known to take shovels off the job and deliberately have them cut down an inch or so in order to lessen the labor of using them.

When a man furnishes his own shovel he will naturally buy

the cheapest he can find. He will use it just as long as there is a plausible remnant of the blade left unless required to discard it after a certain wear is reached. He will not drop his shovel to do other work but will walk 500 ft. or more to his coat and hide it. He thus consumes the employer's time without result. The operating cost of a shovel is at least $2 per day. If the man is permitted to use a shovel of half the full blade length the operating cost is the same but the efficiency is decreased by one-half.

Shovels are abused by being thrown about carelessly, by having heavy tools and materials thrown upon them and by being driven into ties to pull the latter about under the rails. Only the best grade of steel will long withstand the lack of care and heavy duty thus imposed.

A shovel of fair-looking quality may be purchased for 40 or 50 cents but a shovel made from an alloy steel of exceptionally good quality may be had for 90 cents or so, and this will outwear the cheaper shovel at least four or five to one. The introduction of special grades of alloy steel in shovel manufacture has again proved the value of selecting the best of steel for tool uses.

Worn and Broken Track Tools Can Be Repaired Profitably. The cost of new track tools has steadily increased to such an extent that the subject of the repair of worn and broken tools has become one of considerable importance. The general procedure has been very well described in an article in the *Electric Railway Journal* for March 25, 1916, from which much of the following is taken.

Ordinary track hand tools, as a rule, are not reclaimed when they become badly worn or broken, and only such repairs are made as can be readily handled by an ordinary laborer. This is particularly true of large construction jobs where a considerable item of their cost is expended in track hand tools; yet when a job is completed comparatively few of the tools are found to be good enough to turn over to the maintenance forces. Many of these worn and broken hand tools, which are discarded as useless, can be repaired profitably. Experience on some roads has demonstrated this fact, and the ease of making repairs has been considerably facilitated by the introduction of portable welding outfits. While it has been found economical

to repair tools, it is also very important that the repairs be properly made to accomplish the best rsults. It is as essential to good workmanship and efficiency that tools should be kept in proper condition as it is to buy first quality tools. In other words, tool repairs should be concentrated at a single point where one or more men may be regularly employed in putting them in serviceable condition.

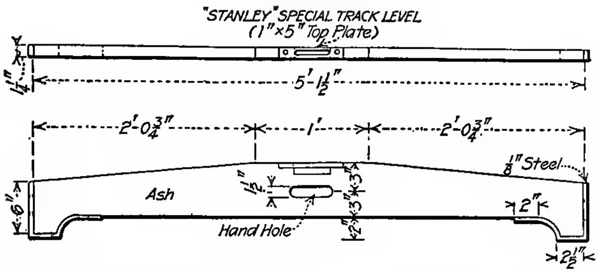


FIG. 3—A SAMPLE STANDARD TOOL PLAN FOR THE LOOSE-LEAF NOTEBOOK

A first-class blacksmith is best qualified to do this kind of work, but it must be borne in mind that not every blacksmith can repair these tools. Experience in making repairs to hand tools is a necessary requisite, hence it is better to employ one man on work of this kind and hold him responsible for the quality of the repairs made.

New Handles Can Be Put on Old Shovels. Specific cases of repairs to hand tools that pay include reclaiming good shovel blades, in which the handles have been broken, by supplying new handles. Handles in good condition may often be had by taking them from blades that are completely worn out. Another method consists in supplying a new cast-iron D-handle to replace wooden D-handles.

Claw bars badly worn, or with one of the claws broken, may be reclaimed by dressing the bar down to form a new claw, or if there is not sufficient stock remaining, a new claw may be welded on. It is also important, and has now become general practice, to keep picks sharp and properly tempered. The cost of the pick was once considered so small that reclaiming the old one was not worth while, but it is now considered economical to do so by welding on new points as needed. Lining bars and tamp-

ing bars may be readily restored to good condition by straightening, redressing and tempering.

Accurate Jack and Drill Repairs Pay Handsomely. Accurate workmanship when repairing spike mauls is very important. An untrue surface makes it impossible to strike a true blow, and an improperly struck blow may bend a spike or cause an accident. An improperly tempered maul soon becomes untrue when the metal is too soft, or if it is too hard pieces may chip off and cause an accident. The same requisites apply to track chisels which primarily must be purchased with steel of proper quality. A poor chisel delays the work and increases the cost of any operation. It is also very important to keep track jacks in perfect operating condition. Where several extra ones are not on hand a bad-order jack may tie up a gang. The track jack, like the track drill, is more expensive than the average hand tool, and it is not general practice to have an unlimited supply of extra ones. It is therefore important that jacks and drills not only be in good order but that they be inspected for defects occasionally, and when repairs are necessary they should be made by an expert mechanic in order to insure results. However, drill bits may be accurately sharpened on the job by the average laborer if the gang tool box is supplied with a Keystone tool grinder.

With no other track hand tools are accuracy and good repair so important as with the usual track gage and level. When these become damaged for any reason the utmost care should be exercised to see that the repairs are made properly, and after the work is completed their accuracy should be checked before they are actually used in track work. Repairs to either of these tools are difficult to make because accuracy is so essential, hence it is especially advisable to have this work done by an experienced repairman. In other words, the repairing of most track hand tools is a job for a specialist if the best results and maximum economy are to be obtained.

Repairing 10,000 Picks at Six Cents Each. As an indication of the comparatively small cost for tool sharpening and repair, it will be of interest to note that the records of one railway covering repairs to picks, lining bars and track jacks for one season show that more than 10,000 picks were repaired at a cost of about 6 cents each, while 6900 lining bars were re-

stored to service at an average cost of 5 cents each and 186 jacks were refitted for service at a cost of 70 cents each. The records further indicate that each jack went to the shop five times during the season. The type of jacks used in this instance cost $8.35 in 1914, hence it is beyond question that the repair was economical.

The cost of tools, supplies, repairs and delivery service varies greatly. Much depends upon the size of the road and its characteristics, particularly as to whether it be a city property with much pavement or a road operating largely in private right-of-way. Furthermore, if a large amount of reconstruction is undertaken in any one season, the cost for tools and supplies will increase accordingly. Consequently there is no measure by which the tool expenses of one system may be safely compared with another. Nevertheless it is worth while to keep track of these expenses with the purpose of being sure that they do not get out of bounds. It may be of interest to state that the cost of tools and supplies may run as high as $100 per mile of single track per year in a busy season, if the costs listed in Table II

TABLE II. EXPENDITURE FOR ROADWAY TOOLS AND SUPPLIES SEASON OF 1917, ON A 550-MILE CITY RAILWAY SYSTEM

Total expenditure for 1917	$48,000.00
Average monthly expense	4,000.00
Cost of tools and supplies	30,100.00
Cost of tool-car service	10,600.00
Cost of tool repairs	7,300.00
Cost per mile single track—tools and supplies	$54.70
Cost per mile single-track—tool-car service	19.30
Cost per mile single track—tool repairs	13.30
Cost per mile single track—total	$87.30

NOTE—Tool-car service was furnished by two tool cars at a charge of $25 per day per car. Tool repairs include repairs to large machines, such as mixers, grinders, arc welders and electric drills.

from the tool accounts for 1917 of a 550-mile city property can be taken as a guide. (The year 1917, by the way, can be considered a very "light" year due to sharp decreases in amount of work done.)

Small tools and supplies, it will be noted from Table II, account for the larger portion of the tool and supply service.

The supply list reads like a stock sheet of a regular hardware store, and everyone knows that small hardware is expensive.

Some of the cheapest things that are used cost a great deal in the aggregate. Lantern globes, for instance, are comparatively cheap in first cost but they are consumed in large quantities. White globes are worth about 6 cents each, while red globes cost about 20 cents each. On city work red globes are used to a much greater extent than white ones. The difference in cost on one property led to an important economy through the use of white globes dipped in a special red coloring preparation. This preparation could be purchased before the war at $3 per gallon. It is now worth $8.75 per gallon. Under these conditions the tool foreman rose to the occasion and consulted with the boss painter who made some experiments and finally produced a red color at a cost of $2.75 per gallon. This holds its color even better than the material formerly purchased and also covers more globes per gallon of color. The former color covered about 350 globes per gallon while the new color covers about 500. This color is made from the following formula: 3 lb. deep permanent red, No. 171 dry, St. George Chemical Company, 25 cents per pound; 1 gal. bronze liquid, $1.75; labor to mix, 25 cents; total, $2.75 per gallon.

Similarly, when the price of high-speed drill bits rose skyward the tool man set about using the arc welder for repairing broken bit shanks and began to get the fullest possible use of the bit points by welding on an added length of shank.

A study of the consumption of kerosene oil on one road recently developed a discrepancy of over 30 per cent between the amount of the oil which should be used for the number of lanterns in daily service and that actually drawn from stock every day. This led to the discovery that some of the oil was going to the homes of the men by devious routes, particularly during the period when oil became very scarce and high in cost. It was also found that there was much waste due to the method of distribution; to carelessness in filling lanterns; to leaky containers and to leaky wells in the lanterns. These discoveries naturally led to a radical change in the whole procedure and effected a large saving.

Good Tool Houses and Tool Boxes Help in Tool Conservation. On long interurban lines, the track tools are usually kept

in section tool houses similar to those used by steam roads, in which case the tools are transported on the section hand cars. The latter are being displaced by gas-driven cars which have many advantages. Where the section is comparatively short or runs out from city or other headquarters, the tools and the section gang are more apt to be transported upon a regular motor flat car, which may remain on the job at the nearest siding during the day. In such cases the car is available for hauling ballast and other needed materials.

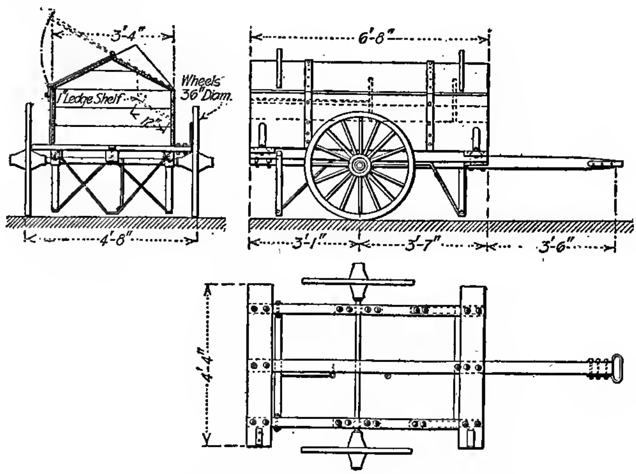


FIG 4—A TOOL WAGON WHICH CAN BE MADE AT REASONABLE COST

It is not practicable in city work to maintain tool houses, and as a substitute each foreman is usually supplied with a tool box or a tool wagon. These should be substantially made and must be provided with exceptionally good locks. The tool boxes are moved from job to job by work cars, usually at night, so as to be ready on the new job when the gang arrives in the morning at a new location.

The tool wagon has the advantage of portability as it can be moved by the men if necessary; it can be towed behind a motor truck or work car, and it can be quite easily loaded upon a work car by the men if skids are provided. A form of tool wagon is illustrated in Fig. 4.

Tool boxes should not be made too large in size with the view of getting all the tools for a gang of fifty or sixty men into them.

Where this is attempted it will be found that it is practically impossible for the men to lift them when loaded and it requires a derrick to place them upon cars for transportation. In consequence the box must often be unloaded and loaded upon the cars when empty, which necessitates much rough handling of tools, greatly increasing breakage and consuming valuable time as well. It is far better to provide two or three boxes of moderate size, each suitable for the average sized repair gang of say twelve to twenty men.

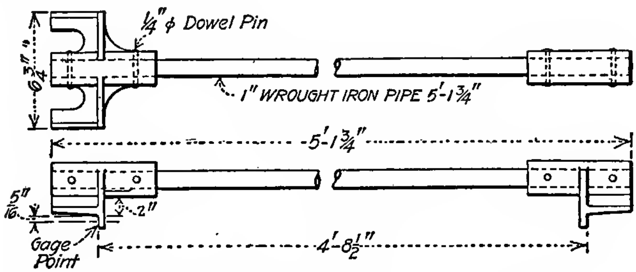


Fig. 5—This Standard Gage Is for Use on Tracks With Guard Rail

Where tool boxes are used it is customary in city work to keep a watchman at the box at all times. He keeps track of the tools, fills lanterns and puts them out on the work and he can make himself useful in sharpening tools on the portable tool grinder. The use of the watchman should not relieve the foreman of his responsibility for the tools and their fitness for service.

CHAPTER V

SUBSOIL AND ITS IMPORTANT RELATION TO TRACK CONSTRUCTION

Among the many depraved traits that inanimate matter possesses, none has caused greater surprise or reflected more severely on the skill of engineers than the behavior of rails and joints since they were made to do service under electric cars, and notwithstanding that a great amount of inventive genius and experimental effort has been expended in improving details of foundations, ties, rails and joints, street railway companies everywhere feel more or less solicitude lest they fail to secure the highest standard of excellence desired.

Although no construction with which we are acquainted meets all requirements in a fully satisfactory manner under all conditions, great advances have been made, and this line of engineering, which heretofore has been considered an humble branch of the profession, is now receiving the attention of the best engineering talent in the country, and some of the modern arrangements represent notable and important improvements over former practice.

The foregoing quotation might have been written yesterday in comment on present-day track construction, but it really was written in 1892 by the late C. B. Fairchild in his memorable work on "Street Railways."

An editorial in the *Electric Railway Journal* not long ago commented upon the important report recently submitted by the committee on stresses in track of the American Railway Engineering Association as follows:

It is well known that railroad track is a structure which has been evolved from previous practice and experience rather than from study and experimental data along scientific lines. It has remained for this committee to earn the enduring regard of the engineering profession through its demonstration that track is subject to known laws and scientific treatment in common with other engineering structures. The proof that track is an elastic structure acting in accordance with Hooke's law is of itself a material contribution to the sum of engineering knowledge.

In the light of this editorial statement we may judge that electric railway engineers need not feel that there is so much reflection upon their skill after all, since it has taken steam road engineers such a long time to discover some of the fundamental laws governing their track construction.

Study of Strength of Materials Necessary in Track Design. At last the fact is becoming recognized that the design of tracks is not a simple matter, whether they are located on private right-of-way or in paved streets. On the contrary, their design calls for the exercise of extreme care and engineering skill in the selection and utilization of a number of different materials which must be united in one structure, just as a great office building must be assembled with materials from many sources. In order successfully to design either a building or a track structure there must be an appreciation of the qualities and strengths of materials combined with the knowledge of their performance under varying conditions which mainly comes with long experience. The principal materials in a track structure before assembly are: Soils, gravel, crushed stone, sand, cement, timber, iron and steel, together with a multitude of paving materials such as granite, wood block, brick, sandstone, slag-brick, pitch and various combinations of bitumen with stone. Some of these items, such as rails, ties, concrete and pavements, assume the position of added items when considered in their assembled state.

It will be the purpose of this and subsequent articles to consider these materials in their relation to the track structure.

Modern Track Dates from the Beginning of Electric Operation. Street railway tracks have been in process of development for more than eighty years, and during the first half of that period progress was exceedingly slow. In fact, there was no radical change in the construction of tramway tracks during the period extending from the introduction of horse cars (about 1832) to the important change in motive power from horses to electricity which began about 1888. With the advent of electric power came the real beginning of the change in track construction which led to the generally accepted types of track in use to-day. It is of interest to note that even in 1892 the main features of the present type of construction were advocated and used to some extent. In fact, a report on proper track construc-

tion was presented to the American Street Railway Association in that year which, if it were edited a bit, could just as well bear this year's date, since it pointed out practically all the essentials which are considered valuable to-day.

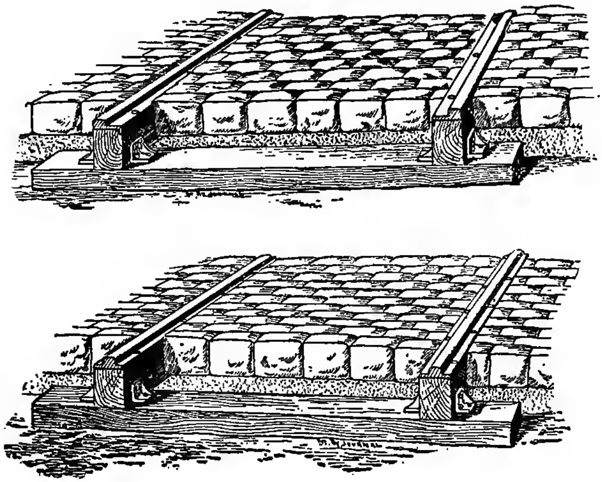


FIG. 6—ORDINARY STRINGER CONSTRUCTION FOR HORSE CAR LINES, WITH CENTER BEARING AND SIDE BEARING TRAM RAIL

We may think we are very modern in our use of concrete in track construction but it was used with tramway tracks in Great Britain thirty or more years ago (see Fig. 9). Even the steel anchor chair for a concrete base, which has been used in the past by the surface lines in Philadelphia, had its predecessor in tracks in Bristol, England, as early as 1892 (see Fig. 12).

The American Street Railway Association report herein referred to also settled the mooted question of "Use of T-rails in paved streets" by saying that they were the best rails to use and should be adopted wherever municipalities would permit. Even the matter of standardization of rails was considered in that year, and it was suggested that there was no need for more than six different rail sections, but it was not until 1914, twenty-two years later, that the association finally adopted four standard girder rails, two guards and two tangent rails. Truly the mills of the gods grind slowly. What a long time the rail mills were occupied in rolling "personal" rail designs for street railway engineers!

Wherever we see a track which is giving good service, we cannot learn why it does so from a casual examination of it as a unit, especially if it is in a paved street. It is necessary to inquire into the details of construction which are combined in the unit. From this detailed examination we may learn how the various elements are combined and we soon find that there

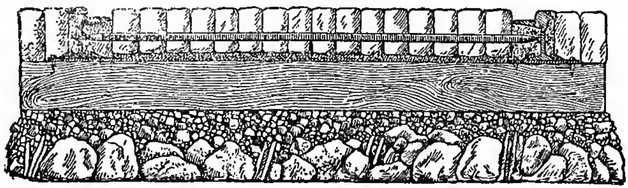


FIG. 7—EARLY ELECTRIC TRACK CONSTRUCTION; STONE BALLAST, 6-IN. RAIL SPIKED TO TIES

are quite a number of factors which have an influence in the design of track structures. Most of them will be found essential in the consideration of both open and paved track, but those

TABLE I—BEARING VALUES OF SOILS

(Compiled by American Concrete Institute, 1914)

Material	Safe Load in Tons per Square Foot
Quicksands and wet soils	0.1 to 1.0
Dry earth according to depth below surface	1.0 to 3.0
Moderately dry clay, confined	2.0 to 4.0
Dry, stiff clay	4.0 to 6.0
Sand, confined	2.0 to 6.0
Sand, compact and cemented	4.0 to 8.0
Gravel, cemented	8.0 to 12.0
Rock	25.0 to 200.0

TABLE II—CLASSIFICATION OF SOILS

(Compiled by United States Department of Agriculture)

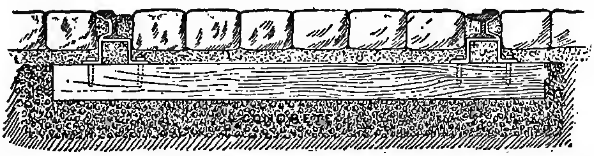
Key	Material	Size mm.	Size mm.	Screens Pass through	Screens Retain on
1	Fine gravel	2.	1.	No. 10	No. 18
2	Coarse sand	1.	0.5	No. 18	No. 32
3	Medium sand	0.5	0.25	No. 32	No. 70
4	Fine sand	0.25	0.10	No. 70	No. 160
5	Very fine sand	0.10	0.05	No. 160	No. 230
6	Silt	0.05	0.005	......	......
7	Clay	0.005	0.000	......	......

By the number of sieve is meant the number of meshes per lineal inch, of wire cloth, woven from brass wire, having the following diameters for

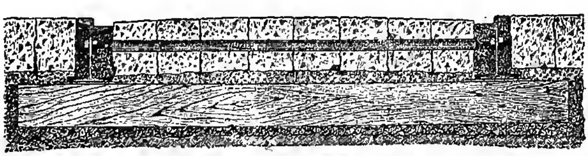
	Diameters
Sieves Nos. 10 and 18	0.0165 inch
Sieve No. 32	0.0112 inch
Sieve No. 70	0.0045 inch
Sieves Nos. 160 and 230	0.0024 inch

which apply to paved track only will be easily recognized. The following list of factors of design is taken from the 1914 report of the committee on way matters of the American Electric Railway Engineering Association upon the subject of proper foundation for tracks in paved streets.

"*Factors Influencing Design.*—From Report of Committee on Way Matters, 1914; (1) Character of subsoil. (2) Bearing power of soils. (3) Drainage of subsoils. (4) Effect on electrolysis. (5) Forms of substructure. (6) Live and dead load



EARLY ELECTRIC TRACK CONSTRUCTION, 6-IN. RAIL ON CHAIRS, CONCRETE BALLAST



EARLY ELECTRIC TRACK CONSTRUCTION (ABOUT 1892), 9-IN. TRAM GIRDER RAIL SPIKED TO TIES
FIG. 8

to be carried. (7) Forms of track superstructure. (8) Pavement. (9) Headway and speed of trains. (10) Street improvements. (11) Subsurface structures. (12) Street and car traffic."

No. 7, forms of track superstructure, is subdivided into five factors which have a further influence upon design; these are: (a) Ties; (b) rail; (c) rail fastenings; (d) rail joints, and (e) pavement.

There is little question but that the most important items are those relating to character, bearing power and drainage of subsoil. The 1914 way committee report above mentioned classified subsoil as the controlling factor in design and submitted a table giving data on the bearing values of soils (see Table I). In 1915 the committee again emphasized these factors and presented a classification of soils (see Table II), as determined by the Department of Agriculture, with a conclusion that the clas-

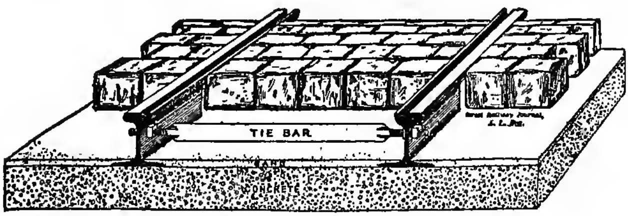


FIG. 9—BIRMINGHAM (ENGLAND) TRAMWAY CONSTRUCTION, USING CONCRETE WITHOUT TIES, ABOUT 1890

sification of soils found in the city streets is desirable. Meanwhile the committee on stresses in track of the American Railway Engineering Association was carrying its experiments forward and now has in preparation a report bearing values of soils which should be of great service.

The 1892 report presented to the American Street Railway Association previously mentioned had the following to say in regard to subsoil and drainage:

The depth of the excavation must be determined by the depth of the rail and tie, plus the space allowed for tamping. The condition of the soil must govern the latter exclusively, but in the reconstruction of the roadbed, where the operation of cars will permit, and in all new work, unless the soil is of sandy character, the following plan will not only provide suitable subdrainage but will also insure permanency: Remove earth to a depth of 8 in. below bottom of tie; roll thoroughly with a heavy horse or steam roller; spread a layer of cinders, crushed rock, gravel or furnace slag 6 in. to 8 in. in thickness and again roll until same is well bedded and leveled. . . . The fact that the material so placed provides a splendid subdrainage is the best argument in its favor and will commend its adoption where soil demands it; for it must be remembered that it is far more expensive to open up and retamp poorly-constructed track than to properly construct and provide subdrainage at the outset.

We would not think of constructing a building of importance without determining beforehand the nature of the soil upon which we were to lay the foundation. If it is good practice to do this in connection with the design of a building, it is no less so when the design of tracks is under consideration, and the premature failure of many miles of so-called permanent track

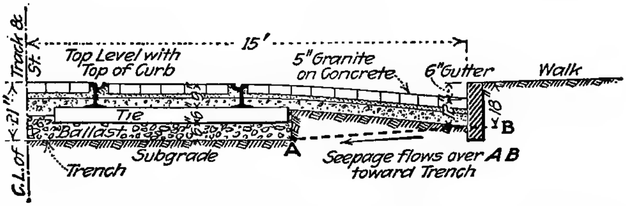


FIG. 10—HOW A TRACK TRENCH MAY RECEIVE WATER FROM ADJACENT ROADWAY

in the past may be laid to either the lack of information relative to the subsoil conditions or to the failure fully to appreciate such information as was obtainable. The fact that tracks designed with due regard to meeting all the controlling elements of design have been made to stand up, after reconstruction, in places where earlier tracks had failed before their time is suf-

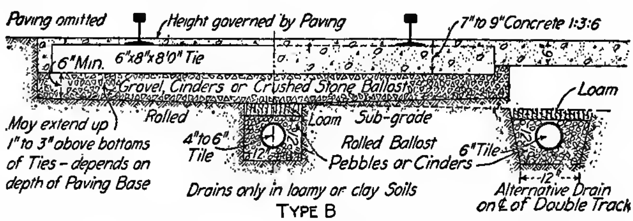


FIG. 11—TYPE B—BALLASTED TRACK CONSTRUCTION RECOMMENDED BY THE AMERICAN ELECTRIC RAILWAY ENGINEERING ASSOCIATION

ficient warrant for the foregoing statement. However, some consideration must also be given to the not infrequent situation which formerly obtained wherein the funds provided for original construction were not sufficient to permit the engineers to incur the expense which would have been necessary fully to meet the conditions.

Ample Drainage Prime Requisite in Track Construction. Ample drainage is the prime requisite in track construction.

This must be provided not only for the subsoil but for the surface in order to prevent infiltration of surface water. Moisture in any form is the chief enemy, and water and frost will cause more damage to tracks than any other agency, bad joints not excepted. It should not be forgotten that the track trench takes on the form of a drainage ditch for the rest of the street,

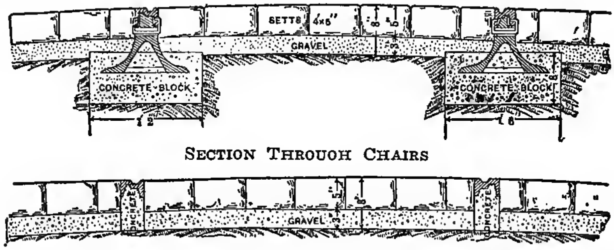


FIG. 12—EARLY USE OF STEEL YOKES ON RAIL ANCHORS IN CONCRETE IN BRISTOL, ENGLAND

even though it is backfilled with the track structure and paving materials. This trench usually has a depth of from 15 in. to 21 in., depending upon the depth of the rails and ballast, and it will be seen from Fig. 10 that the bottom of the trench may be 9 in. below the bottom of a 6-in. macadam or other shallow pavement even at the gutter. With deeper pavements this depth becomes less, but even with a 5-in. granite pavement on

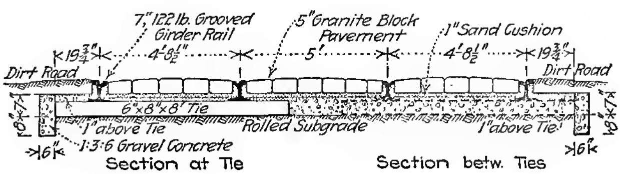


FIG. 13—A METHOD OF PREVENTING DAMAGE TO ROADBED FROM SEEPAGE OF WATER

concrete, and 7-in. rails, wood ties and 6 in. of ballast, the difference in levels may be at least 1 in. Hence, there is great opportunity for stray water from the surrounding surface of the street and adjacent property to seek the track trench.

How much water actually reaches the trench in this way is dependent upon the character and condition of the pavement and of the soil. How much of it stays in the trench also de-

pends first upon the soil and then upon the drainage provisions. A comparatively inexpensive scheme for preventing seepage of surface water to the track trench from the adjacent roadway surface where the latter is not paved and the soil is known to be a water-retaining clay, is shown in Fig. 13. This consists of a dependent curb constructed as a part of the concrete base for track pavement and extending about 8 in. below the level of the bottom of the ties. In the particular instance shown it was not thought necessary to use ballast upon the subgrade, but the precaution was taken to consolidate it thoroughly by rolling with a 10-ton roller.

In most cases where the soil is of such a character that ballast of gravel or crushed stone must be used, it will also be found that the ballast alone should not be depended upon to provide sufficient under-drainage. If the ballast is well compacted, especially by rolling, water will not flow through it readily. Furthermore, the soil works up through it more or less after a time and tends to prevent the passage of water. It is for these reasons that most of the designs for modern ballasted tracks now make due provision for subsoil drainage by means of tile drains. It will be seen from the foregoing discussion of drainage provisions that dependable data upon the bearing value of soils will be of great assistance in connection with the design of tracks. Meanwhile, the classification of soil by mechanical analysis combined with the tentative bearing values of soils now available should be used by track engineers in every case where there is any doubt as to how to meet uncertain soil conditions.

In treating subsoil preparatory to laying the tracks, it will often be found that the practice of rolling will be of material assistance. It is stated by the way committee that a more even distribution of load is effected, that the bearing power of the subsoil is increased, that rolling should be done wherever practicable under working conditions and warranted by the kind and condition of the subsoil, and that it is especially desirable wherever there has been much disturbance due to sewers and cross trenches under the tracks. Since uniformity is desirable in the track structures as a whole, it seems to be a fundamental principle of track design that the first place to secure uniformity is in the subgrade upon which the track is to be founded. There

is no question but that this can best be done by rolling, with moist soils. Occasionally it is necessary also to add broken concrete upon which to operate the roller. Even where the ballast is to consist, in part, of a concrete slab as sub-ballast, the rolling is just as essential in order that the slab will obtain a uniform bearing throughout. It should not be forgotten that even

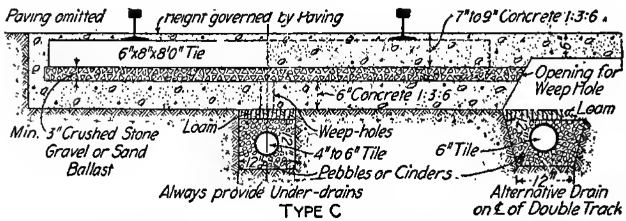


FIG. 14—TYPE C—CONCRETE SLAB SUB-BALLAST TRACK CONSTRUCTION PROPOSED FOR USES WITH VERY POOR SOILS

though the subsoil can be stabilized by rolling, it is essential that it be kept in this state by ample drainage provisions.

An example of the type of track construction wherein drainage is properly provided is shown in Fig. 11, which is the recommended, type B design as adopted by the American Electric Railway Engineering Association in 1915. In the meantime the

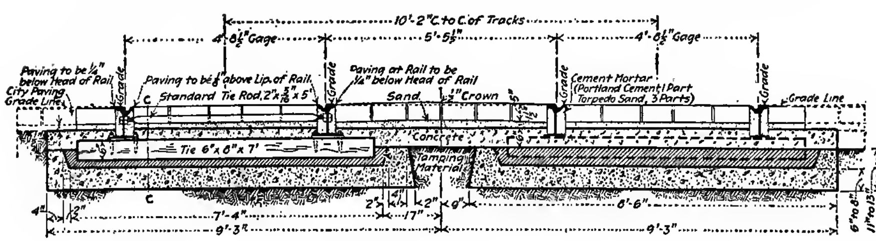


FIG. 15—CROSS-SECTION OF TRACK CONSTRUCTION ON TWELFTH STREET, CHICAGO

way committee presented another design known as type C, utilizing a concrete slab sub-ballast with similar provision for underdrain, as shown in Fig. 14. It was intended for use on very heavy water-retaining soils and other uncertain ground.

The Engineering Association did not care to adopt this as a recommended design, although its merits were recognized, because of the fear that it might be forced upon railway companies by municipal authorities in many instances where such an

expensive construction would be unnecessary. However, it is a type which is used voluntarily to a considerable extent under soil conditions which almost demand its use. Thus the concrete slab feature was employed recently in Chicago, as will be seen from Fig. 15, which is reprinted from an article describing its use, which appeared in this journal for March 30, 1918. The article in question, unfortunately, does not state what provisions were made for under-drainage other than to say that the construction was built upon a lake sand fill about 9 ft. in depth which was used to fill up cellars of houses over which, through a street-widening scheme, it was necessary to lay the tracks.

CHAPTER VI

AUTOMATIC TRACK SWITCHES RELEASE MEN FOR OTHER WORK

The traffic requirements of street railway car operation upon lines having very close headways necessitate the employment of some means for turning the switches in order to minimize delays at junction points. With car schedules under which the cars do not reach a closer spacing interval than three minutes it is possible for the motorman to turn the switch by hand with his switch iron, without causing undue delays to following cars, but where the interval is less than three minutes it becomes necessary to employ a switchman. But the cost for this amounts to $1,000 or more per year for each switch, and it was the desire to cut down this operating expense which led to the employment of mechanical and electrical devices as substitutes. The introduction of various forms of prepayment and center-entrance cars, which impose door-opening and closing duties upon the motorman and render his constant presenre upon the car desirable, is another factor which in recent years has contributed to the quite general adoption of switching devices.

There is no question as to the fact that the installation of electric track switching mechanisms will result in an operating economy at any location where traffic conditions warrant the employment of a switchman only in the rush hours, say for a total period of six hours per day. This saving effected is indicated in the accompanying Table I.

TABLE I—COMPARISON OF COSTS FOR ELECTRICAL AND MANUAL OPERATION OF TRACK SWITCHES

Type of Operation		Hourly Cost	Annual Cost	Annual Saving
Manual Operation, $3.50 per day of twenty hours	.....	$0.160	$1,277.50	....
Electrical Operation.				
Device cost, installed	$285.00			
Interest at 5%	14.25			
Annual maintenance expense	100.00	.013	114.25	$1,163.25

The operating costs used in the table are believed to be very conservative. A recent questionnaire in *Aera* developed a range in maintenance costs for electric switching devices of from $35 to $100 per year, with an average of the four costs reported, of $65 per year per switch. It is believed that $100 will closely approximate the maintenance cost, exclusive of interest, for these mechanisms on any road where there is a traffic which requires an average of not less than 500 movements per switch per day. It is to be noted that the electric apparatus is available for operation all of the time, while the use of switchmen is mainly confined to from six to eighteen hours per day.

The first attempts to produce such devices were solely along mechanical lines and the Patent Office undoubtedly has many recorded patents for mechanical devices in its files. Nevertheless a purely mechanical device has never met with favor nor has one ever been produced which has met with sufficient success to warrant its general adoption in electric railway service. According to information from Fred Bland of Sheffield, England, this statement covers the British situation also.

The first automatic track switches were used on horse car lines and consisted of two platforms resting on opposite ends of a pivot lever, somewhat like a see-saw. One platform was at the right hand side of the switch point while the other was at the left. If the switch was to be thrown to the right the horses were pulled over so that they walked on the right hand platform which depressed under their weight, throwing the switch to the right. A heavy ball weight rolled over at the same time, holding the switch in place. If the movement was to be to the left, the horses were pulled onto the left hand platform with the similar results. The chief difficulty with this device was due to freezing and clogging with mud.

Another one of these early mechanical devices is shown in Fig. 16. It was produced in 1892 by C. E. Carey, then master mechanic of the Dry Dock, East Broadway & Battery Railroad Company, now a subsidiary of the Third Avenue Railway, New York City. As will be seen, it depends upon the use of a projecting lug which would be engaged by the wheels of certain cars only, the latter being equipped with wheels having a wider tread or special flanges.

With the advent of electric cars a mechanical device was de-

signed to be put in the ground, using a cam shaped surface to be engaged by a pedal attached to the car platforms and depressed by the motormen. It was not successful because the mechanical part in the ground would freeze and get clogged, while the mechanism on the cars became broken by contact at too great speed with street obstructions. The requirement of parts to be attached to the car was also a disadvantage.

The early electrical devices attempted to follow steam road practice and the operating magnets were placed on the trolley pole at the curb, with connections by means of rods or wires to the switch point. Undoubtedly the placing of the magnets on the poles was for protection against moisture. One of the first

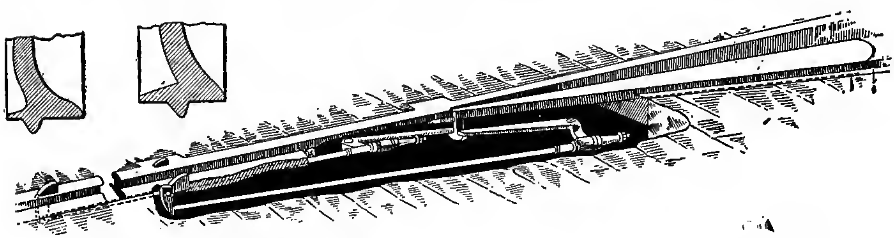


Fig. 16—Early Mechanical Form of Track Switch Used in New York City

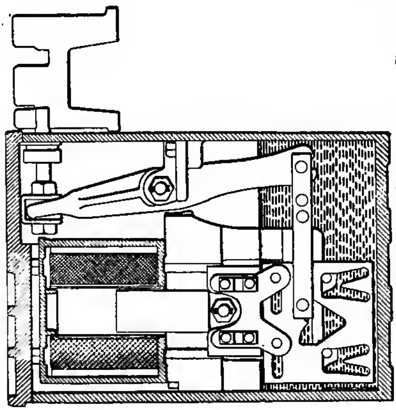
electric mechanisms of this kind was the Porter device installed in Detroit, Mich., about 1895 or 1896. Another one of similar design was installed in Brooklyn about 1900 by Spangler. The chief trouble with these designs was due to the fact that the ordinary stuffing box did not keep the water out and the mechanical parts would freeze up.

Meanwhile Squires, Cheatham and Baldwin were developing their devices. There is a record of two installations of the Baldwin switch in Brooklyn in March, 1897. They were put on the market by the New York Switch & Crossing Company. It is of interest to note that they were still in service until 1913 when they were removed for replacement with a more modern type. Some details of this device are given in Fig. 17 in which a wiring diagram is also shown. Squires had his device in service in Springfield, Mass., and Cheatham installed his first device in operation in Louisville, Ky., about the year 1899.

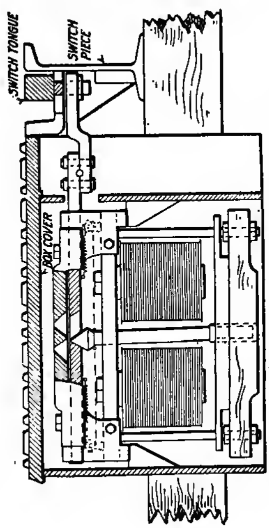
These types placed the magnets in a mechanism box in the ground at the switch point, thus simplifying the device and the Baldwin type provided for drainage connection to the sewer, in

order to protect the magnets. Cheatham's device placed a water-tight case around the magnets for protection and the Squires device was also designed to be water tight.

The early Baldwin device was operated by an insulated sec-



Switch Box with Reversing Cam Plate



Section A-B (See Fig. 17)

Section of a Pioneer Electric Track Switch

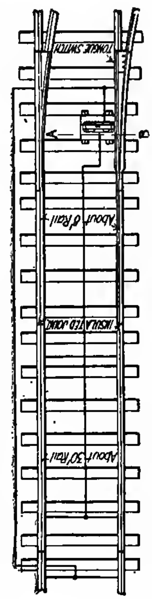


Fig. 17—Wiring Diagram for an Early Type of Electric Switch

tion of the track ahead of the switch, while the Cheatham and Squires mechanisms were operated by overhead contactors. The Baldwin later changed to the overhead contact also. There are three other devices which appeared between 1900 and 1903. These are the Kitt which is and has been used in Denver almost

exclusively; the Wooley used in East St. Louis and elsewhere to some extent, and the Collins (American Automatic). The Kitt had two solenoids in the ground box and the circuits were controlled by an electro-mechanical current reversing device. The Wooley had two contactors on the trolley wire and was operated by current "on" or "off" under one contactor or the other as the direction required. The Collins had one solenoid in the ground box and the switch was thrown by a cam plate reversing device, also in the box. (See Fig. 17.) The first Collins devices were designed for underground conduit work in New York and were first used there in 1902. The first Collins devices for regular trolley work were installed in Brooklyn in 1903. The early type of this device was contained in a watertight box, using an ordinary stuffing box. As this gave some trouble it was superseded by the mercury seal.

It will be seen from Fig. 18 that the modern devices have abandoned the insulated section of track as a factor in their operation and have returned to the overhead wire instead, using some form of contact-making device, operated by the passage of the trolley wheel as a means for setting up circuits which actuate the mechanism.

The development of curb and tower control began about 1904 when the use of automatic switching devices commenced to make headway. The first of these were installed in the Jersey City Terminal of the North Jersey Street Railway and at the Williamsburg Bridge Plaza in Brooklyn. The first complete electro mechanical interlocking for surface street railways was devised by Collins and installed in Washington in 1908.

Perhaps the most radical change in electric switch design is the recent anti-splash type, operated by a small electric motor in the street box, as designed by Collins. This was introduced in 1916 and the first installation was made in Brooklyn in that year. Besides preventing splashing troubles, the device is designed for electric locking to prevent splitting and untimely operation by following cars. The same type of electric lock which is used with this device can be used with other Collins devices for locking switches against two-car train operation.

Present-day devices consist principally of four main parts, namely, the contactor, the circuit-changer, the fuse box and the main street box. Sometimes the contact device has the circuit-

changing device attached thereto, and in some cases the circuit changer is mounted upon the trolley pole at the curb. A diagram of wiring of a complete installation is shown in Fig. 18. Views of several street-box mechanisms are shown in Fig. 19.

In general the operation of the switch tongue is accomplished by means of solenoids located in the street box, but a recently developed type does this by means of a small 110-volt motor and

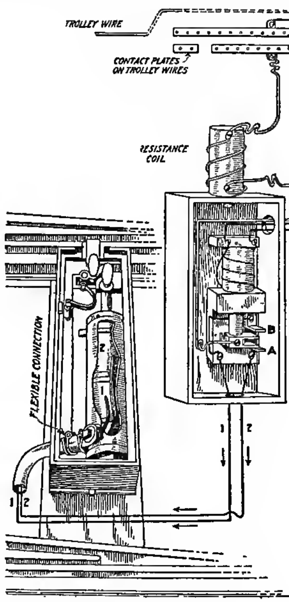


Fig. 18—Wiring Diagram of a Complete Modern Electric Switch Installation

trains of gears also located in the street box. (See Fig. 19.) The several devices shown in the figures will be recognized by those who are familiar with such apparatus, but it is not the intention here to indicate either that these are all of the devices available or to express any preference whatever as to the types of apparatus shown.

It is of some interest to note in passing that at least one modern design of street box has the solenoids in a vertical position substantially as they were in the early type, although the means for actuating the switch tongue are radically different.

Electric Switches in Underground Conduit Operation. The

application of electric switching devices to underground conduit systems on surface lines presents some difficulties not found in ordinary surface operation, since it is necessary to operate the leaves of the conduit slot in conjunction with the switch tongue, thus requiring the movement of the additional weight of the leaves. In consequence a very powerful and rugged apparatus is needed. A drawing of the mechanical connections

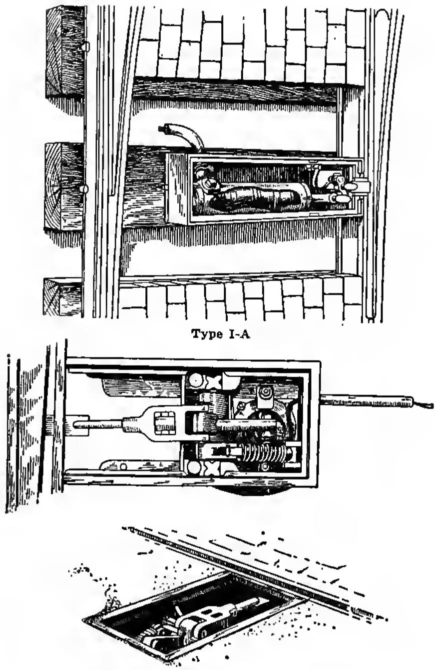


FIG. 19—TYPES OF MODERN STREET BOX MECHANISMS FOR ELECTRIC SWITCHES

of the principal type of apparatus in general use on conduit lines is shown in Fig. 23. The type shown is in service in New York, Washington and London. It operates as follows:

The switch throwing mechanism has but one solenoid and the motion is transmitted in the two directions by means of a reversing cam plate. The mechanism also has contacts mounted upon it for use with interlocking and these operate the indicators in the tower. In the underground conduit type one of the conductor rails has an insulated section. One of the wires from the

solenoid is connected to the live conductor rail and the other is connected to the insulated section.

If the motorman desires to throw the switch, current is applied to the car while the plow is on the insulated rail and the solenoid of the mechanism, being in series with the car motors, becomes energized, its plunger is lifted and the cam plate causes the switch to be thrown. When the car leaves the insulated rail the plunger and cam plate fall back by gravity and re-set to throw the switch in the opposite direction. If the switch is

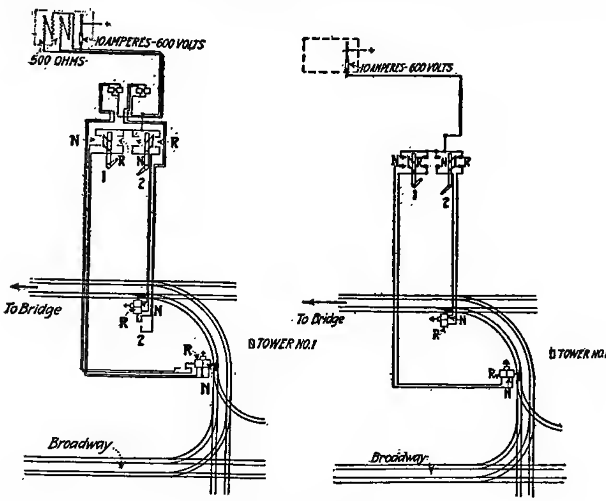


Fig. 20—Wiring Diagrams; at Left, Tower Control; at Right, Cubb Control

not to be thrown the motorman passes over the insulated section with power off. If the switch is thrown by hand the reversing cam plate also reverses. There is a toggle movement with heavy spring attached to the switch throwing mechanism to act as a semi-lock and hold the switch point and leaves in the slot rigidly in the position to which they are thrown.

Severe Conditions Must Be Met. There are several rather rigid conditions which electric switching devices must meet in street railway service. They should be composed of the fewest possible parts; they should be simple enough in mechanism and electrical connections to permit the average man of intelligence to maintain them; they must be waterproof as far as the parts in the street are concerned; they must prevent any possibility

of splitting the switch; they must not require more than ordinary intelligence from the motormen, and they should be non-operative under the combined current required for light, heat and air compressor circuits. Other desirable features are these: Means should be provided to prevent splashing of mud and water upon passengers and pedestrians; it should be impossible for a following car to throw the switch between two trucks of a car which may be passing over the switch; it should not be absolutely necessary for the motorman to see the position of the

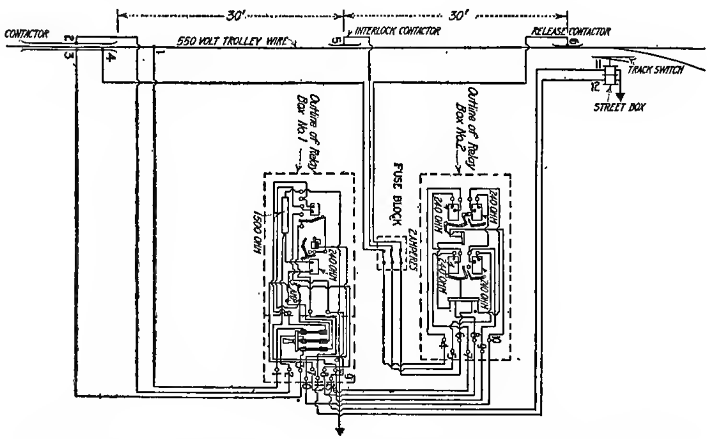


Fig. 21—Wiring Diagram of Interlocking for Electric Switch Operation Under Two-Car Train Service

switch in order to operate it correctly, and it should be impossible for a car to burn out the electrical apparatus by standing with trolley pole directly under the contact device. In two-car train operation, where both cars have their trolley poles in contact with the wire, it is absolutely essential that the second car of the train cannot operate the device.

These somewhat numerous requirements may be summarized into five main factors which should be considered in the selection of automatic switching devices. These are: (1) Perfection of service; (2) economical maintenance; (3) simplicity of design; (4) simplicity of installation, and (5) reasonable first cost.

Where Most of the Operating Troubles Come From. A particularly troublesome factor in connection with electric opera-

tion of switches arises from the switch pieces themselves. There are at least eight types of switch tongues which the mechanism may be required to operate. The tongues may vary in weight from 90 lb. to 240 lb. There are at least as many more methods of heel fastenings for switch tongues. It is obvious that the mechanism will work better with certain types of tongues and fastenings than with others. It follows that, in order to obtain the best results, some attention should be paid to the selection of the switch pieces with a view to securing those types which are the most reliable for electric operation. It will even be found advantageous to install the particular switch selected in all cases where electric operation is to be provided.

It has also been noted that track switches which are electrically operated are subject to more abuse from the cars and require more attention for minor repairs, such as "heel tightening," straightening or "shimming," than those not so operated. This is probably due to the fact that the cars are operated over them at greater speeds, since it is often unnecessary to stop the cars before passing over the special work. On the other hand, if the motorman must set the switch by hand, he must stop to do so and then he cannot do otherwise than pass it slowly. There are at least thirty different things which can cause failures, making no allowance for car-operation failures (man-failure). A careful record should be kept of these in sufficient detail that repeated defects or faults will be noted promptly and steps taken to obviate them. It has been observed during a period of two years that the failures may be roughly placed in three general classes: (1) *Mechanical,* including only the failures due to faults in the track switch or associated therewith, such as loose or tight tongues, bent or broken tongues, loose or bent connecting rods and links, dirt or snow and ice in switch pocket; (2) *Electrical,* including all burnt-out magnet coils or relays or resistance tubes, blown fuses, wires detached from contactors, worn contactors, defective circuit changers, worn trolley wheels, and weak tension springs in trolley bases; (3) *Operating,* such as fast operation under contractors, failure to use or not to use power at the proper time, failure to preserve proper distance from car ahead. The items of worn wheels and weak tension springs are really mechanical or equipment troubles, and failure due thereto must not be counted against the ap-

paratus. Of course operating failures are not apparatus failures. The three groups described have been found to classify themselves into the following approximate percentages of the total "failures" reported yearly: (1) Mechanical, 15 per cent; (2) electrical, 75 per cent, and (3) operating, 10 per cent.

In connection with failures it may be said that the proper measure of electric switch performance is based upon the total number of car movements per failure without trying to classify the causes. Even this method admits of some discrepancy because very busy switches are subject to excessive heating from

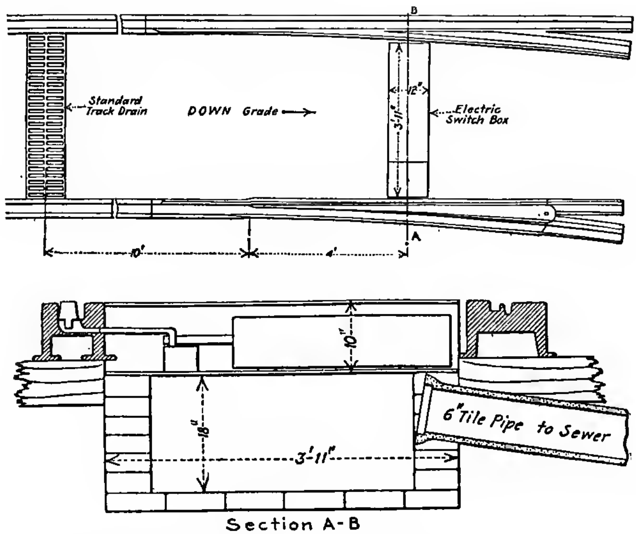


FIG. 22—TRACK SWITCH INSTALLATION SHOWING PROVISION FOR DRAINAGE

their almost constant use and extra trouble may be expected at such locations.

When due consideration is given to the very onerous conditions under which electric switching devices are required to work, their performance in respect to reliability is truly remarkable. It has been observed that, upon one system having 115 devices in service, the average number of operations or movements is 863 per switch per day. The greatest number is 3026 and there are thirty-five which have from 1000 to 2000 movements per day. All the others operate over 500 times daily. There are about 38,205,000 movements per year, and it

has been noted that performance records indicate failures due to defects in the device in proportion of one failure to over 46,000 operations as an average for all the switches. On another road there is a record of 117,000 operations to one failure.

The answers to a recent question in the American Electric Railway Association "Question Box" indicate that the electrical department of most companies assumes the maintenance of what may be considered the electric parts, beginning with the contactors at the trolley wire, and extending through the relay boxes on the pole to and including the actual magnet coils in the track box at the switch. The only work required of the track department is the adjustment and maintenance of the actual mechanical parts of the tongue switch piece. On one or two roads, however, the track department takes charge from the tongue switch up to and including the relay box on the pole. This is somewhat unsatisfactory, since it divides the responsibility for electrical maintenance between two departments, leading to trouble in placing responsibility for failures and consequent duplication of inspection and emergency calls. There is also a third party, namely, the transportation department, which must assume some of the responsibility for "troubles," since failure to observe the rules on the part of the motormen can cause much trouble and damage.

Automatic Switching at Terminals and Other Congested Points. There are locations on large city systems where car traffic and street traffic are so heavy, and the track switches are so closely grouped, that it is impracticable to attempt automatic operation of the switches. These points of congestion will be found to have a car headway of from forty-five seconds to one and one-quarter minutes. In most cases the operation by switchmen is attended with difficulties, such as dodging cars and vehicles and at some personal risk. These conditions are overcome by the use of tower or curb control devices used in conjunction with the switch-throwing mechanisms of the automatic type.

The tower control consists of a switch control cabinet and resistance board. The operator has in front of him in the tower an indicator board upon which is mounted a model layout of the track and switches, each model switch being electrically operated by contacts in the real switch into positions always in

correspondence with its own. Mounted on the control cabinet are control handles, one for each switch and numbered the same as the model switches on the indicator board. The handles have a rotary movement of about 60 deg., being locked in position by a simple latch which the operator must lift to move the handle, thus preventing unintentional movement. Each handle operates a cam which in turn engages a swinging latch of a magnetic blow-out, quick-break switch which makes and breaks the circuits to the solenoids in the switch-throwing mechanisms in the street, throwing the switch in the direction in which the control handle is rotated. Wiring diagrams of tower control and curb control installations are shown in Fig. 20.

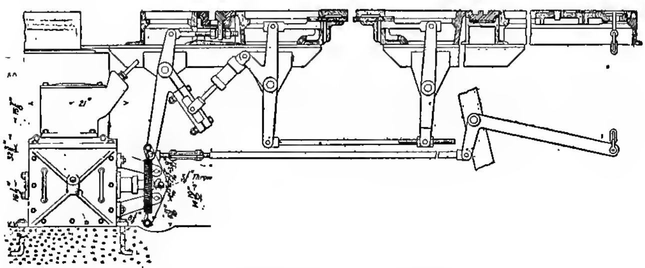


Fig. 23—Mechanical Connections of Automatic Electric Track Switch for Conduit Lines

In cases where the operator has many switches to handle it becomes advisable to lock the control handle so that it cannot be moved while a car is passing over the switch. This is prevented by installing two small contactors in advance of the frog on the wire. The first locks the handle by means of a small magnet mounted on the control cabinet and the second contactor unlocks it by similar means after the car has passed the switch. This is a simple form of interlocking, and the difficulties created by two-car trains are now being overcome by a similar arrangement applied to the regular automatic devices. A wiring diagram showing how this is accomplished should be of interest. One is presented in Fig. 21.

Apparatus for Operation of Derails at Crossings. A situation somewhat analogous to the traffic conditions at congested points is found at busy surface crossings of steam and street railway lines. At these places, in addition to the crossing gates,

it is a safety requirement that the crossing be protected by derailing devices. Where there is a man required to operate the gates, there is no added labor cost for operation of derailing devices. The electric switch mechanisms lend themselves readily to adaptation for this service. The control device as well as the operating mechanism is substantially the same, and it is only necessary to add a semaphore to complete it.

The maintenance of electric switches, where there are very many to care for, will require the exclusive services of from one to five men. When their number reaches a hundred or more the latter number of men will have plenty to do as a rule, and they are provided with an automobile for quickly reaching trouble points and covering a large territory. In connection with maintenance the following description of methods for overcoming troubles during the winter season is worth quoting. It is from an article by P. Ney Wilson, covering the practice on the lines of the Connecticut Company at New Haven.

Preventing the Freezing of Electrically Operated Switches. The problem of preventing freezing of switches on the lines of the Connecticut Company is a difficult one on account of the wide variation of temperature and weather conditions. The New Haven lines alone have twenty-seven electrically operated switches and sixty patented spring boxes of various designs. Aside from salting, which is a common practice, we find the following procedure very satisfactory.

1. When new switches are installed at any season of the year, the tongue and heel tightening device is removed, oiled and carefully adjusted, and the heel box is filled completely with oil-soaked waste.

2. Electrically operated switches require regular inspection and adjustment. A settling box is built under them, connected directly to the sewer. When the switch is installed in a water pocket a track basin is placed so that it will catch sand and dirt before it reaches the switch piece. Salting in snowy weather and oil in dry weather will keep these switches free for satisfactory service.

3. "Anti-kick" spring boxes not equipped with a stuffing box are cleaned and oiled and then filled completely with oil-soaked waste plus a little salt. The waste is packed loosely around the working parts, and care must be taken that it does not interfere with their operation. This treatment applied twice during an ordinary winter will practically eliminate trouble due to freezing.

4. In all spring boxes in which plunger connections operate through a stuffing box the tight compartment should be kept filled with compressor oil.

5. As to the salting of switches at night, we find that the sending of one or more cars over the lines is the cheapest and most effective method of keeping the switches free. These cars salt switches, run through all special work not in regular use and operate all automatic switches.

A Reasonable Amount of Maintenance Necessary. In conclusion, it may be said that electric switching devices, like all other mechanisms, cannot be expected to work perfectly under all conditions and at all times. There are too many adverse factors constantly working to put them out of commission. It can only be expected that a fairly high degree of operating perfection will be obtained, and the measure of success in this will be almost wholly dependent upon the care which is given to the apparatus by the maintenance organization. It must not be expected that the devices will maintain themselves. On the contrary, they require that reasonable amount of inspection and adjustment which should be given to all mechanical and electrical devices.

PART II

POWER GENERATION

By HARTLEY LEH. SMITH, recently Engineer of Tests, Brooklyn Rapid Transit System; now in Engineering Department, New England Power Co., Worcester, Mass.

CHAPTER VII

ELECTRIC RAILWAY POWER PLANT AND ITS PERSONNEL

THE power supply of an electric railway comes either from an electric power plant devoted exclusively to the individual railway's use or from a power plant carrying railway load as a part only of its total load, the remainder being lighting load and industrial power load for manufacturing purposes. While slightly more than one-half of the electric railways to-day get their power from plants devoted exclusively to their own use, and in fact owned and operated by them, the tendency is very rapidly growing to forego exclusive power supply and purchase from a power company.

The forms in which electric power is generated for electric railway use are direct current at 550 and 650 volts, direct current at 1200 volts, direct current at 2400 volts, alternating current, three-phase at high voltage with substation transformation, and alternating current high voltage single-phase with distribution to the overhead contact system without transformation. The single-phase distribution just mentioned is in reality single phase distribution from three-phase generators in practically all cases to-day.

Generation of three-phase current in this country is at 25 cycles or at 60 cycles per second. Other frequencies are so rare as to be altogether negligible. This is by no means true in other countries. In England, for instance, there are four or five frequencies in common use.

Until very recently alternating current for railway use, whether transmitted to converter substations or distributed to high-voltage, single-phase trolleys, was invariably generated at 25 cycles. Lately, however, the 60-cycle, 550 to 650-volt railway converter has been developed and large amounts of power are now being generated at 60 cycles and transformed to direct

current for railway motor use. It is indeed the 60-cycle railway converter operating at 550 to 650 volts which is making possible the movement away from exclusive power generation, and the substitution for it of power purchased from the general power company. The general power company generates at 60 cycles, since its load has been lighting and industrial power, and 60 cycles alone is a frequency suitable for lighting. Stations generating at 25 cycles are therefore either those devoted to electric railway load or they are stations situated in those very large cities where the congestion is so great as to make feasible the entire transformation to direct current form before distribution of light and power to consumers' circuits.

An Efficient Plant Is a Specialized Plant. So much for alternating-current generation and distribution. Of the forms of direct-current power, those at 550 to 650 volts, 1200 volts and 2400 volts, it may be said that they are generated in power plants devoted exclusively to railway use, the amounts of such power sold as a general supply for industrial purposes being so slight as to be quite negligible.

Classifications of course cannot be made too rigid. There are, for instance, very many electric power plants in this country with entirely distinct groups of generators devoted to the specific purposes for which they are exclusively fitted. Such plants constitute, so to speak, two or more generating stations under one roof; they are not typical of modern practice. They are examples neither of the specialization which spells economy, nor of the wellnigh universal adaptability of the extremely modern stations which also spells economy.

Direct One-Man Management Is Rare. Of the organization of the personnel of electric power plants it may be said that there is very wide variation when considered in any detail; standardization of such organization even along very general lines has as yet by no means come. It is doubtful whether any distinction could be substantiated between the organization of personnel in railway power stations and that in others. One very broad and significant generalization can however be made; the division by a sharp line between electrical and steam (engine and boiler room) responsibility. The four walls of a power station but rarely house an official fully responsible for both classes of apparatus and service. Of course responsibility for

these two cardinal services merges always somewhere in the company organization in one man. Very nearly always, however, he is a man stationed among the other company executives. In all but really large companies, where complexity and differentiation of organization naturally multiply, he is almost sure to bear other executive responsibility also. Very often he bears very many other responsibilities, as general manager. Very often, too, in companies somewhat larger he is electrical engineer and is in charge of electrical distribution and often indeed of rolling stock also, although this last is certainly less common than formerly. Really large companies organize quite differently, with much specialization as size increases.

As for companies of average size, and even much less than average size, so sharp a distinction runs between immediate first-hand charge of steam and electric operation and maintenance control that there is but one answer. Men considered capable of ambidextrously handling both are scarce. The thin ranks of such men are growing nevertheless visibly larger. Why so? Well, it is a fact that the boys from the technical schools of fifteen years ago are boys no longer now.

An electric power station has its chief engineer; it has also its chief electrician. These are not responsible one to the other. That is the point I have been making; responsibility merges above. A consequence is that chief engineer and chief electrician have their own separate organizations. It is largely so that this dualistic responsibility perpetuates itself. Power stations are manned largely by men who grow up in power stations. A man grows up as a steam man or as an electrical man. After a while he gets to the top of the steam or of the electrical department. Do I know that the water tender in the boiler room reads in his technical paper the circuit connections of a three-phase generator? I do know it. I am not writing of the power station a bit in the future but of the present-day power station.

Organization Varies with Plant Characteristics. Of the detailed organization inside an electric power plant no standardized scheme can be drawn up. Certain very broad distinctions are however fairly clear. In all but very small plants there are electrical operators and electrical maintenance men. Rarely do electrical operators do repair work. On the steam side, however, a watch engineer and a monkey wrench are much together;

likewise a boiler room engineer and a tube cleaner. In quite large power stations it is true there is apt to be considerable distinction between plant operation and maintenance, with sometimes an assistant chief engineer responsible for maintenance under the chief engineer, while the watch engineers, operating men, remain responsible directly to the chief engineer.

A very important phase of the steam plant organization bears upon the relationship between engine or turbine-room force and the boiler-room force. At one end of the scale, that of the small plant, there is the engineer and the fireman or firemen, with nothing dubious as to who gives and who takes orders. But at the other end of the scale, the very large plant, the question of unity or cleavage of organization is sometimes decided one way, sometimes another. The question is whether the chief engineer deals directly with the boiler-room force or more or less through the ranking man or men of the engine room. Very rarely probably does the engine-room man find himself unconcerned with certain features of boiler-room operating practice, such as banking and starting up of boilers to suit the changing number of engine-room units in operation, the maintenance of uniform steam pressure, etc. Very often, however, no engine-room man is held in any way responsible for boiler repair work.

A vast deal is written nowadays about the superior significance of talent, real engineering talent, in the boiler room; that it is in the boiler room that plant economy is made or lost. We are told that in the boiler room is the opportunity for the big operating man; that there a man's work from hour to hour is worth amounts of money to his company so vast compared with his pay that his pay might be anything at all. We are told also that the increasing, very rapidly increasing, introduction of individual boiler units of very great size is rapidly putting this claim upon the basis of actual practice. We are told that the really technical man is demanded; that this company or that company is going after graduates of engineering schools of rank and that in the boiler room such young men will do the thing as it should be done. This sounds well. The scheme is grounded in very excellent logic; but does it really work? Would such men stay, and if they stayed would they do what is expected of them? In the first place there are a lot of things a technical man, a technical graduate, doesn't know. He knows

boiler operation, or if he doesn't he learns it very quickly and well. But maintenance he doesn't understand because a whole lot of it consists of "tricks"; in other words, it is a trade. He can learn that, too, but life is short and the American technical graduate rises all too quickly to wait for that. Before you can very well get track of some of them you find that they are running power stations themselves. If that is so they must bluff it just a bit for a while, you say? Well, yes, but then we said above that they are Americans, did we not?

Technical Men the Hope of the Boiler Room. What then is the hope of the boiler room? I really think it awaits the day of the thoroughly technical chief engineer. That day hasn't come, but it is coming. If a man knows the field intimately at present he knows that the full advent of the day is distant even yet. And the reason for this is simple, it will not be here until the older men have left the field. Even that will not be enough; men must be graduated in larger numbers than at present, and a greater proportion of those graduated must continue working as engineers. The young fellows who are in power stations now in capacities more or less vague and nondescript, and there are many of these but many more are needed, must stay and grow up and find themselves eventually in charge by a sort of inevitable inheritance. Then, too, certain fast-vanishing prejudices which now exist must be banished forever.

And when the day comes when power plants, in practically all cases, are in charge of trained technical men, will economy have improved and if so how will it have been improved? After all, the technique of power station operation is not of great complexity. Compared with a scientist's field the day's work of a power plant engineer may be arduous, but it is not complex. Indeed, its very simplicity is a handicap, for it can hardly attract the ablest men. Scarcely any of the essentially technical features of power generation are entirely outside the knowledge of men operating power stations to-day. They have heard of them at least, although their grasp upon the underlying principles may not be of the firmest. The chief difference is that in that future day the men running power stations, technically trained men, will more truly believe in these principles. They will believe them to be more worth while; they will believe them to be more practical. Then, too, we must not forget that their

task of execution will be easier. If the chief takes to knowledge and "drinks" it, what will the "boys" be doing?

Station Duties Differentiate into Boiler, Steam and Electrical. But to come back to the power station of the present. On systems of size there is almost sure to be, on the electrical side, some sort of system operator or chief operator, distinguished from the chief electrician and his direct organization in that they deal with electrical operation inside the station while he deals with the relation of the station to its external load, so to speak.

On the steam side under the watch engineers and possibly turbine engineers in large stations there are oilers for the main units and often engineers and oilers for the steam auxiliaries. The details of organization depend very largely upon the design of the turbine or engine room, that is, the proximity and accessibility of the auxiliaries from the engine or turbine floor. An important class of men, distinct in a large station, are those who take care of the maintenance of the auxiliaries of the main units. The need of such men is particularly urgent where very high vacuum is maintained in turbines provided with surface condensers and reciprocating dry-vacuum pumps.

In the boiler room the simple organization of a small station changes considerably to a complexity in stations of very large size. Besides firemen there are sometimes head firemen who see that instructions are observed and the general level of skill maintained. Often the water level is not controlled by the firemen but by water tenders. Over water tenders or head firemen, or both, there are sometimes boiler-room engineers, responsible as a general thing as operating men to the watch engineers of the turbine room or engine room. Of course, size of the plant is the chief factor. In many fairly large plants the chief engineer exercises directly many functions which in plants of very great size he exercises through subordinates.

To discuss organization broadly is to note that it deals in simple manner or complex, depending on size of plant, with the sorts of energy transformation and the apparatus by which the transformations are accomplished. In a steam-operated plant there is one beginning but there are two endings. The beginning is the coal handling. One ending is the removal of the ashes, the other is the delivery of the electric energy to the

transmission lines. Many sorts and kinds of apparatus make up the total. To enumerate briefly the principal links we find coal hoists, coal crushers, coal storage plant, facilities for coal delivery to the boilers, coal feeding into the boilers, coal-combustion appliances and aids, the stacks, flues, economizers and other appliances for caring for the products of combustion, the ash-dumping and ash-removal facilities, boilers for steam generation, superheaters for the increase of efficiency, feed-water pumps and heaters, feed-water purifiers, steam piping, main engines or turbines with their auxiliaries, condensers, condensing-water pumps, air pumps, oil pumps, electric generators, oil switches, switchboard control, electrical measuring instruments, outgoing feeders. All of these present their problems for organization aside from their problems of operation.

CHAPTER VIII

THE TESTING ORGANIZATION OF ELECTRIC RAILWAYS

In considering the work of a testing department the first question which merits discussion is whether or not such a department is worth while and economical. To justify itself it must result in the more systematic and efficient handling of certain things which are indubitably worth while.

The tendency of the times is to make tests. When it is decided that necessary or desirable tests shall be made with frequency, a testing department is created; until then, such tests as are made are handled by outside laboratories.

Electric railway tests, like all others, may be classified as those which are necessary and those which are desirable. Of necessary tests, practically all electric companies, railway or otherwise, are agreed that watt-hour-meter calibrations shall be so classed. The division line between necessary tests and desirable tests is an extremely elastic one.

If a testing department exists the tests which are considered either necessary or desirable, and, being so considered, are made, depend really very intimately upon the relationship of the testing force to the departmental organization of the corporation. Tests might, for instance, be very closely associated with purchases. Where this was true the testing organization would be intimately connected with the purchasing organization. On the other hand, tests made on materials purchased are much more likely than not to be made on materials bought under technical specifications: *i.e.,* engineering specifications. Such specifications are naturally prepared by the engineering department or departments. Thus a natural link is at once found between the testing organization and the engineering organization.

Modern testing, of course, is an engineering matter. As a matter of fact, it is now fairly established as a branch of engineering. I need only point out that one of the great national engineering societies, the American Society for Testing Materials,

is one devoted specifically to testing. So a testing organization is almost sure to be an engineering organization, manned by engineers. In an overwhelming majority of cases the testing organization of any corporation constitutes a part or branch of one or more of the engineering departments of the corporation. It might be thought that if there are more or less separated engineering departments in a large organization the testing force would in some way be equally associated with or related to them all. Such would, indeed, be the logical arrangement.

Tests may deal with materials or machines. The distinction is quite real. There is, for instance, the American Society for Testing Materials, cited above, but as yet there is no national society concerned particularly with the making of tests on machines, and perhaps there never will be. There are, instead, the codes of several national engineering societies dealing with the methods of making tests on some of the important classes of engineering apparatus. For instance, there are "the power-test code," adopted by the American Society of Mechanical Engineers, and the "standardization rules" of the American Institute of Electrical Engineers.

Among other broad divisions into which the work of a testing organization of an electric railway may be classed, so far as new material and apparatus are concerned, these three seem pertinent; first, continuous supplies; second, apparatus installed for extensions and betterments, purchased under guaranteed-performance specifications, and tested for acceptance; third, materials and apparatus on trial.

Of the first class a long list might be written, but some very common illustrations are coal, oil, condenser tubes, boiler tubes, incandescent lamps, trolley-line material, car wheels, axles, bolts, cement, paint, etc. In the second class a partial list including turbines, condensers, boilers, automatic stokers, centrifugal pumps, blowers, static transformers, rotary transformers, circuit breakers, high-tension cables, etc., might do. Of the third class, coals and oils other than those which have been customarily used, all sorts of steam specialties, lightning arresters, rail bonds, and many other things, might be mentioned as illustrative.

Deterioration Tests Another Function of the Testing Department. Another large field of work for the testing force is in inspecting material and apparatus during manufacture. In

some of the most advanced organizations this work receives great prominence. As an important contribution along this line I would cite the paper entitled "Testing Is Not Inspection," by W. A. Aiken, read at the annual meeting of the A. S. T. M. in 1908.

Another class of work for the testing organization is in making tests to detect deterioration of the efficiency of apparatus which has seen considerable service. Such tests are of much aid in securing reasonable maintenance of the original efficiency of the apparatus throughout its life. Such tests, for instance, might show that the blade clearance of a turbine has increased and turbine castings become warped, both contributing to higher steam consumption; that pump impellers and casings have suffered erosion, with resulting falling off of efficiency; or that engines have developed valve and piston-ring leakage, clearly evident in indicator cards systematically taken and analyzed.

A still further field for the department is in tests made on apparatus for the detection of developing obsolescence. This is intimately related to the evolution of more highly efficient forms of apparatus designed for the same work. As illustration, the ageing of transformer iron may be cited, with its effect on substation efficiency, or as measured by uneconomical iron losses where potential is continuously maintained regardless of load. Still another illustration is in the detection of increasing current transformer errors due to ageing of iron, with its effect on watt-hour-meter registration.

Tests Related to Improvement of Operating Conditions. Among the lines of work for the testing department which are of importance are those which deal with studies of operating methods. for instance, in power-station work there are tests made for the purpose of revealing those operating methods which will yield high efficiency under fundamentally controlling conditions of operation; that is load factor, extreme range between maximum and minimum loads, etc. Take, for example, the matter of banking boilers. This operation involves losses, but, depending upon the furnace equipment, some boilers will give astonishingly high over-all efficiency when steaming at low rates. These same boilers may show a falling off in efficiency to disappointingly low, but nevertheless legitimate, values in hours of heavy peak loads.

Merging closely with the above are studies which attempt to show the operating conditions and methods which will bring about the ultimate desideratum of power-plant economy; that is, such operation as will cause the summation of the fixed capital charges and the operating charges to be a minimum.

For instance, it does not at all follow that a turbine should be operated at its most economical water rate. Important papers on power-plant operation, based upon a realization of all these general principles, have been read before some of the national engineering societies, and certainly in the future this subject will receive a great deal more detailed attention than formerly.

Another set of general tests includes those designed to give clear-cut information as to the methods of operation and maintenance which will favorably affect the heat balance of the station as a whole. For instance, there is the important problem of exhaust steam from auxiliaries; that is, as to the excess or deficiency of it, and the action taken regarding such excess or deficiency. In many stations to-day provision has been made for the connection of the auxiliary piping system, not only to the feed-water heaters but also to the low stages of one or more turbines, thus allowing considerable practical control of the heat balance.

Certain variations in operating procedure are dictated by seasonal variations throughout the year. Two sources of heat-supply (when the heat balance is rigorously considered) fluctuate very greatly with respect to entrance temperature throughout the year, namely, the feed water as taken from the city mains, or other outside source, and the intake circulating water. The feed water, in so far as it comes from an outside source, is able to absorb a far greater quantity of exhaust steam in the winter than in the summer; and similarly the seasonal variation in intake circulating water is so great as to make large changes in the quantity of circulating water which are most economical in winter, on the one hand, and in summer on the other.

Routine Testing of Water and Other Power Plant Elements. Apart from tests and studies which have classifications such as outlined above, there are in the modern power station certain tests which do, or should, constitute essential parts of daily operating routine.

Foremost among these are tests which deal with water treatment. Where turbines are used, it is only under rather extreme circumstances that surface condensers are not used. The only justification for surface condensers is the use of the condensate as feed water. Where feed water has to be purchased from a municipality, the potential saving in the use of the condensate from surface condensers becomes enormous; so large that to forego it is prohibitive.

The use of condensate from surface condensers, however, involves many a problem. Except where the power station is so fortunately situated as to have unusually good condenser circulating water, I do not think it is possible to continue long the use of water from the hot wells of the condensers as feed water unless such use of it is controlled throughout by daily laboratory tests. Condenser tubes will develop leaks, and, as such leaks are the result of attack of the circulating water on the tubes, water so leaking becomes a contaminating influence in the feed water, and will cause trouble if not controlled.

Tests for Impurities in Condensate and of Conditions in Condenser. The sort of tests which in the aggregate constitute a system of adequate control is an extensive subject in itself. Certain fundamentals, however, can here be set down. When the tube leakage in any one condenser has become too great the entire hot-well water from that condenser must be thrown away until such time as the condenser can be shut down and repairs made. While it continues in operation with its water so contaminated by condenser-tube leakage as to prohibit its use as feed water an equivalent feed-water supply must be obtained from the alternative source, in general from a municipality, at a rather high cost per cubic foot.

The water from the mains of a municipality seldom constitutes an ideal boiler feed water; in other words, it compares unfavorably with the hot-well water from a condenser in which the leakage is slight, or even negligible. Therefore, it becomes a problem of correctly establishing the standard of allowable leakage through the condenser tubes into the hot well, after which the hot-well water will be temporarily thrown away.

Next in the order of these problems is that of scale prevention. The hot-well water will normally come to the feed-water heaters with certain amounts of condenser leakage water in it, as outlined

above, and will consequently, in practically every case, be a scale-forming water. So also, in general, will be the water taken from the municipal mains or other outside sources. Prevention of objectionable scale is a necessity, and laboratory tests of some sort are essential to control the water treatment, whatever the treatment may be. After the water has been treated with reasonable satisfaction in this respect, it may, as a result, be of such nature as to induce priming. Hence, water tests for the specific purpose of avoiding priming difficulties become quite as essential as those which deal with the scale prevention treatment.

Among the tests which are practically essential parts of daily operating routine are those connected with the maintenance work involved in maintaining first-class vacuum on large turbines. The last quarter-inch of vacuum obtainable in turbine practice is of the most urgent importance. The items which should have daily watching and control by tests are the adequacy of flow of circulating water, the air leakage, and the efficiency of air removal.

The adequacy of flow of circulating water is affected by the obstructing material which may have accumulated in the water boxes because it was not entirely caught at the intake screen. Daily tests should therefore be made to determine the temperature rise of the circulating water, which data in connection with simultaneous turbo-generator load data suffice for calculating closely enough for the purpose the quantity of water circulating. This will be found to undergo quite marked reduction between intervals of water-box cleaning or condenser-tube scraping. A fixed schedule for such work is not satisfactory because obstruction due to accumulating trash is itself irregular, due very largely to the effect of weather conditions on the source of condensing-water supply, usually a river.

The air leakage into a condenser due to obscure causes is variable, and quantitative measurements are an aid in the general work of vacuum maintenance. Some years ago, in large power stations, the practice of using the device shown on page 132 became rather general. It embodies the principle of a gas holder or tank. The air, leaking into a condenser and withdrawn by a reciprocating dry-vacuum pump, is discharged into the device, causing its movable element to rise as the air accumulates in it above a water surface. The time of rise is measured with a stop-

watch, and the quantity of air is calculated in cubic feet per minute, or other convenient unit. The power stations which have adopted this practice look upon it as well-nigh revolutionizing the problem of insuring that their condensers are free from objectionable air leakage. Such a device can be used immediately to render large air leakage evident.

There is, however, another aspect which perhaps has not had quite such general recognition, namely, the effectiveness or efficiency of air removal. All of the air which leaks into any condenser is removed by the air pump, otherwise there would be an accumulation of air in the condenser, and the unit would soon go to high pressure. To show what is involved in effective air removal it is only necessary to name the means used to measure it. To this end the valve in the air suction line between the air pump and the condenser is closed, and a reading is taken of the vacuum which the pump is able to "pull down" against the closed valve. If the pump is in proper operating condition it will naturally "pull down" a very high vacuum. Often enough, however, it will do nothing of the sort, and maintenance or repair work is accordingly at once indicated as urgently necessary on the pump parts themselves.

Some Factors in Maintaining High Vacuum. Some very interesting relationships exist, indeed, between the effectiveness of air removal, the quantity of air leaking into a condenser (and hence removed actually by the pump), the vacuum accordingly maintained in the condenser, and the type of air pump. There are on the market several kinds of air pumps embodying the ejector principle, and so constituting a radical departure from the old-line reciprocating pumps. Among these types great differences exist, as can be seen from curves plotted to show the vacuum possible to maintain in a condenser under given conditions of turbine load, circulating-water temperature and quantity of flow, in terms of the quantity of air leaking, and accordingly removed by the pumps.

Most reciprocating pump equipments in actual service are really of greater capacity than is ordinarily recognized. When such pumps are so maintained as to give effective air removal they will take out of a condenser the quantity of air leaking into it with such relative ease as to make the extent of air leakage of rather secondary importance. That is to say, if a reciprocating

air pump is kept in fine mechanical condition one need not worry greatly over the quantity of air getting into the condenser.

With certain ejector pumps, however, the operating characteristics seem quite different. The vacuum which can be maintained in the condenser itself is not only a definite but one might say that it is a considerable function of the quantity of air leaking into a condenser. In such cases great care needs be taken to keep the condenser air leakage down to a low minimum if the pump has small capacity. If it has large air-removing capacity it is apt to make considerable power demand.

Attention may also properly be called to the fact that it is with just this sort of equipment that no effective device has as yet been developed which will permit of measurement of the air leakage in absolute terms. This, however, is not such a great disadvantage as might be supposed, because it is still possible to judge the condition of such an ejector pump by measuring its vacuum-pulling ability against a closed suction valve, and immediately afterward the vacuum which it can maintain when actually removing air from the condenser.

The rather steep line, previously referred to, connecting its vacuum-pulling ability with the quantity of air removed, suffices to determine whether the air leakage into the condenser is moderate or whether it is large, and thus needs work to bring it down again to moderate values.

Tests of Boiler Operation. An extremely simple matter which can be controlled by daily testing and which relates to one of the most fundamental and by no means negligible sources of loss of power station efficiency is the determination of the combustible matter in the ashes. Undoubtedly many power stations are following this matter up, as the relationships between true ash in the coal, combustible in the ashes as dumped, and resulting loss of potential heat are well understood.

Of great importance, also, although not so obviously connected with testing, is insuring the cleanliness of the heat-absorbing surfaces across which the gases from the furnace flow and through which the heat is transmitted to the boiler water. As, however, the fluctuations in gas temperatures leaving the boiler are given more attention than formerly, and very frequently are recorded automatically, it generally follows that a testing force becomes considerably involved in such studies.

In this connection it certainly would not do to omit some mention of the determination of the composition of flue gases. A few years ago the writing of papers on this subject amounted to nothing less than an epidemic. If we could gather statistics showing what young men in testing work in power stations really are doing probably the time spent analyzing flue gas or adjusting apparatus which itself automatically analyzes flue gas would appear high up on the list.

Calibration of the Watt-Hour Meter May Produce Large Cash Savings. Turning attention to the tests which may really be called essential for power station operation, we are confronted first by watt-hour-meter calibrations as mentioned earlier. In many cases, increasing in number, the corporations owning power stations are dependent for their fundamental income upon the accuracy of watt-hour-meter registration. In most electric railway power stations watt-hour-meter registration accuracy still affects only the accuracy of certain statistics, such as the economy figures of the power station itself, the energy consumption of the rolling-stock per ton-mile, figured from the power station switchboard, etc. But more and more every year the registration of watt-hour meters measuring energy supply for railway use is intimately related to cash payments, as the generating end bills the railway for energy as if it were a separate organization.

Probably accuracy of registration of railway watt-hour meters in service averages lower than in lighting or industrial power service because of the more violently swinging character of railway loads. Large railway power systems naturally suffer less from this handicap than small ones, but large systems are in general worked with substations, and the substation load is usually marked by severe fluctuation. Naturally this is true in a special degree where subway or elevated train loads are carried. The testing force of a railway power company therefore finds itself concerned with the problem of overcoming the handicap and attaining high accuracy in watt-hour-meter calibration. Quite special instrumental means and methods have accordingly resulted.

Insuring Accuracy of Switchboard Instrument Measurements. In a more general way the electric plant tests, which may be considered in the strictly necessary class in that they are

either taken care of by an organized testing force or at less frequent intervals through the agency of outside testing organizations or departments of manufacturing companies, are those dealing with calibration and repairs of the switchboard indicating instruments. Where there is an organized testing force this work on a large system is apt to keep several men fairly busy. The work requires considerable skill if it is to be done efficiently, that is, at lower cost than that involved in having it done by the repair departments of the manufacturing companies.

The requisite skill of the men varies naturally with the type of instrumental equipment, some makers using much more delicate construction than do others. As a general proposition, however, on systems of ordinarily large size really high maintenance standards can be obtained far more cheaply if the instrumental repair work is done by a testing force. Such repair work is so closely connected with calibration, that is, work in which errors are detected and corrected without the necessity of repairing broken parts or replacing them with new parts, that the two kinds of work are generally done by the same men. The instruments requiring this sort of attention on an a.c.-d.c. system include ammeters, voltmeters, static voltmeters, synchroscopes, frequency meters, indicating wattmeters, etc.

Calibration of Ammeter and Other Shunts. An organized testing force is apt to find itself pretty intimately concerned with the measurement of the ohmic resistance of meter shunts. Such shunts are subject to incidental deterioration. Now and again such a shunt will be overloaded and the avoidance of such overloading may temporarily be impossible. It may as a result suffer change in resistance.

More serious than this, however, because more likely to occur, is possible change in resistance due to handling during installation. Ammeters working on shunts are, of course, in reality millivoltmeters, and the nominal potential for full scale deflection is generally on record expressed in terms of millivolts. Ammeter calibration itself therefore resolves into nothing more than the calibration of so many millivoltmeters. It is idle, however, to work upon this basis unless it is really known that the shunt resistances either actually have their nominal values or some other values which may be looked upon as substantially fixed for reasonable intervals.

I am speaking, of course, of those systems where effort is made to attain thorough-going accuracy founded upon a substantial basis. In this connection, however, it is worth while to point to the increasing use of the mercury type of watt-hour meters. If charges between one electric company and another or an electric power company and a railway company are to be based upon mercury-type watt-hour meters the resistances of the shunts ought to be measured *in situ*. This measurement of the resistances of shunts after installation is somewhat difficult and complicated. In large stations or substations it is a matter needing not only proper instrumental testing equipment but considerable skill.

There Is Work on Gages to Be Done Also. Turning to the steam plant, and considering tests which may be called necessary, the pressure gages naturally come in first for attention. There are indeed other ways for a manager to be assured that steam pressures are really what the station log indicates than to have a testing force to calibrate steam gages. But it is true that in a large station where there are many gages the average of accuracy is apt to be low unless an organized testing force is looking after them.

If such gage testing is done it is naturally done all along the line—water gages, air pressure and draft gages, vacuum gages, etc. In a large station with considerable instrumental equipment, maintenance and calibration of such instruments have just about the same status as in the case of electrical instruments. That is, to a considerable extent repairs are made by the testing force, and the general maintenance of instrumental accuracy where repairs are not necessary provides a considerable amount of work. To specify definite instruments may seem to be criticising certain of them, but broad experience will not lead to such a deduction. If there is a plentiful supply of steam-flow meters, recording pressure gages and thermometers, not to speak of CO_2 recorders, there is apt to be plenty of work.

Adjustment of Relays Naturally Falls to the Testing Department. A somewhat different viewpoint in considering the testing department from any of the above may be had by considering certain apparatus, and the adjustments and tests made upon it relating to automatic handling of emergency conditions. Going back to the electric plant, an extremely important case in

point is that of relays operating oil switches of the high-tension system. The practice of different operating companies seems to vary very widely with respect to the underlying ideas upon which relay adjustments are made, and there is also much variation in the plans used to insure reliable operation. Companies differ also in the extent to which they have pushed experimental investigations along this line.

Where there is a testing force it naturally handles the matter of relay adjustments. The ease, accuracy, and reliability of such work have been increased in recent years by the development of a device which uses the cyclic variation of current of an alternating system as the quantity against which the operation of relays is checked, rather than against time measurements with a stop-watch. In using this plan it is only necessary to see that the frequency of the system at the time of making adjustments is substantially normal.

Adjustment of relays with a stop-watch is unsatisfactory because the only truly significant thing about relay action is how it acts when the actuating current is large. When it is large the relay action is quick and the time interval so short as to render stop-watch measurements unreliable. With a cycle counter accurate measurements of very quick relay action are at once attainable. Hence it becomes possible to adopt adjustment schemes which not only make provision on paper for properly selective action between relays on different parts of the power transmission circuits but which actually allow of the attainment of such selective action.

In practically all inverse-time relays in actual use at the present day, excluding only certain very old types, the relations between time and current are very definite. These characteristics are more flexible than are sometimes supposed. A well-designed system for the several relays at different parts of the power transmission circuits will show provision for selective action based upon a given margin of relay reliability at any currents within the limits of possible action. It will also include in its provisions the time required for the successive operation of oil switches as distinguished from relay operation. All this can be shown in a group of curves.

The testing force making relay adjustments will work with these curves so that, although the testing loads during successive

calibrations may not for one reason or another always be identical, the adjustments given the relays will be such as will make them operate in a definitely known manner. The need for, and the great operating benefit derived from, accurately working selective relays on a complicated system is such that a testing force engaged in the work of adjustment is used also to keep track of the maintenance of adjustment in a systematic and routine manner.

To take an illustration from the field of matters more or less akin to the above discussions of electrical maintenance, let us consider the subject of safety valves. Safety valves, whatever else they are, are mechanisms of sufficiently complicated principles of design to give them in certain service characteristics not widely appreciated. Ordinarily one thinks of "popping pressure" and "blow-down" as about the whole safety-valve story, but a testing force can sometimes reveal unexpected limitations of types a bit antiquated, indicating the desirability of modernization.

The Organization of the Testing Department. With respect to organization of the testing force, its three divisions are manifested at once. Incidentally they follow rather inevitably the broad division lines which appear in the field of engineering education in so far as that field has direct relations to power plant service.

The young men engaged in testing work are, generally speaking, graduates of engineering schools. Probably no such testing force is, however, exclusively composed of such men. The schools turn out among others graduates in electrical engineering, in mechanical engineering and chemistry or chemical engineering. The testing work of such power plants naturally falls into these three classes. There is no small amount of interchangeability between the electrical and mechanical engineering graduates, since all electrical engineering courses teach much concerning mechanical engineering and mechanical engineers are taught a whole lot about electrical engineering. This interchangeability is such as to be able to bear considerable strain in actual service. Exigencies of organization building and the natural capabilities and adaptabilities of individual men, which after all override any rigid educational demarcation lines, bring about now and then applications of this sort of strain. The writer once had

simultaneously, for instance, an electrical engineering graduate in charge of steam testing and a mechanical engineering graduate in charge of electrical testing.

In the line of chemistry interchangeability hardly works. Electrical and mechanical engineers are taught chemistry but they are not chemists. In the testing work of a small or moderate size electric power plant a man not a specifically graduated chemist often does sufficiently well, but in the more highly specialized work of really large plants no great success could be expected. Much of the testing work of a mechanical nature around an electric power plant is fairly simple, but some is not. Where any approach to general quantitative analytical work is made a real chemist is required.

The writer ventures to predict that in the not distant future another branch of the engineering educational field will be tapped in manning the testing force of large electric railways, that of metallurgical engineering. The extension of the metallurgy of steels in recent years, for example, has been very rapid. Likewise, special steels have been developed for special uses and complicated heat treatment is given to such steels during their manufacture and afterward. There is a growing recognition of the value of inspection during purchase of large orders, and a general extension of research in industry. The rapidly extending use of metallography in such work will demand the service of young graduates of the metallurgical schools.

It would also seem possible that the testing work of electric railways will find place for another branch of engineering, if such it may be really called, efficiency engineering. Of course all engineers think of themselves, let us hope rightfully, as in some degree efficiency engineers. Further, it is only too well known that many rather ill-advised activities of so-called efficiency engineers have been such as not to commend themselves to the practical minds of many very capable executives—and electrical railway executives on the whole are very practical. Still there does seem hope that the wisest among efficiency engineers will overcome the fairly justified prejudice with which a good many of the cult are now viewed, and we may find some young representatives of the class substantially established among the others in the prominent testing organizations in the electric railway field.

CHAPTER IX

TESTING AND TREATING POWER PLANT FEED WATER

In this and succeeding articles we shall deal with the raw materials of the power plant, in this one with water. In line with strictest logic water cannot be called such because kinetic energy in electric form is the one finished product, and potential heat of the fuel (its B.t.u. content), is the one raw material. The very strict logician would even find fault with this statement, reminding us that potential heat, while a very real entity, is not a material substance, raw or otherwise. Such a logician would also tell us that even a hydro-electric plant converts, fundamentally, the *potential energy* of the water into *kinetic energy* in electric form. He would bring out that in both the steam driven plant and the hydro-electric plant, water serves as a material medium for energy transformation, and in both plants all of the water that enters leaves again as water. Even in the steam plant water, manufactured if you like into steam, is in the end reconverted into water.

But putting aside such fine distinctions, and thinking only of the steam plant, let us consider some of the problems with which plant operators are faced due to the numerous and all-important ways in which water, by changes of state and of temperature, serves its purposes in the production of kinetic energy in electric form.

Impurities in the Water Are Sources of Preventable Trouble. These problems raised by water handling are chemical problems. In many ways hydraulic engineering problems are real enough in steam-electric plants. They are not entirely problems of the designing engineer either, although very often if he would give them more attention as technical hydraulic problems the operating man would get a few additional credits in the station thermal-efficiency accounts. But the operating man is faced continuously with some all-important chemical problems due to

water. If water were just water these problems would disappear; but all water in the power plant has contained in it other substances in solution or suspension, and they make the trouble. Even hot-well water in the act of condensation absorbs gases. Thus the power plant engineer's chemical problems are ever present.

Power plant water will corrode, it will scale, it will prime. It has to be kept from doing all three things, or so nearly kept from doing them as to make their evil effects of small consequence. There is still room for the better accomplishment of this even in the best operated of present-day power plants.

Water may corrode condenser tubes, ferrules, tube sheets, boiler tubes, boiler drums and internal feed pipes. Condenser circulating water is all too often corrosive, in fact is usually so. It is used in such vast amounts that correction of its corrosive properties is absolutely prohibitive in cost and is never attempted. Sole reliance is placed on selection of metal for the tubes, ferrules, and tube sheets of condensers which will be least affected consistent with reasonable cost. But in connection with the requirement last mentioned it must be remembered that the cost of condenser tube corrosion is all too often entirely unreasonable, so that any costly tube which would stand up would be cheap in the end.

The corrosive properties of the feed water can be controlled; so also can its scale-forming properties and likewise its priming properties. With proper handling of these three the boiler-room-water chemical problems, at least, are solved.

Water "Concentration" in the Boilers Must Be Kept Down. Boiler water will not corrode if it is alkaline, but not too alkaline. It will not scale if its sulphates are converted to carbonates. It will not prime if undue concentration of feed water is prevented in the boiler drums. This last point is of very great importance. To hear some power plant engineers talk one would think that they ran their plants on two separate and distinct kinds of water, namely, condenser circulating water and boiler feed water. Instead they actually use three separate and distinct kinds of water: condenser circulating water, boiler feed water and *concentrated water inside the boilers*.

A natural question at this point is: How much does boiler

water concentrate? The answer is furnished by noting how much water the boiler-room engineer blows out of the boilers through the blow-offs, or how much leaks out through leaky blow-off valves in addition to the water which is intentionally blown off. If it amounts to 5 per cent the station thermal efficiency account must be looked into, and, of course, the cost account also. If as little as 1 per cent, high concentration in the boiler water, with its baneful effects, may be expected.

Watch the Sodium Chloride of the Concentrated Water. Now the simplest of all means exists, if chemical test facilities of very elementary sort are available, by which the power plant engineer may determine very accurately the percentage of feed water blown off (or blown off and leaking away combined) or its reciprocal, the concentration of the feed water in the boilers. Practically all power plant water contains common salt, sodium chloride. Sodium chloride does not undergo any changes in the actions and reactions which make other chemical substances in the water the source of so much power plant trouble. Therefore if the amounts of sodium chloride in the concentrated water of the boilers and in the feed water are determined the one figure will be much higher than the other and the ratio will be the ratio of concentration of the boiler water compared with the feed water. Its reciprocal, expressed as a percentage, will be the percentage of water blown off (or blown off and leaking combined). Right here it may be noted that if track is kept of the water intentionally blown off the difference between the percentages determined as above will be a direct and very excellent measure of the quantity leaking through valves which need repair.

Feed Water Analysis Is Not Enough. The problems of corrosion prevention and scale prevention are jointly handled by maintenance of proper alkalinity. However, there is much confusion and misinformation on this subject. It is usual where wáter treatment is undertaken to base the treatment on analysis of feed water and to "let it go at that."

Such procedure is wrong, as can be illustrated in this way. One does not run an automobile rapidly down a straight road by manipulating the steering wheel so as reasonably to insure that the plane of the front wheels is parallel to the length of the car, taking the worm gear and sector, reach rods, etc., all

into due consideration. One keeps his eye fixed down the road ahead, and the steering wheel is moved a little this way and that so that the sides of the road, as they seem to speed past, make no objectionable approaches to nor recessions from the car. In short, one's attitude is pragmatic, and so it should be with water treatment.

Analysis of the feed water, elaborate or otherwise, is the proper step for a beginning. A decision must first be reached as to *what* should be used as treating agents. The analysis, elaborate or otherwise, might almost as well be qualitative as quantitative, and the result will indicate what should be used. This should be used as the automobile is steered. The *concentrated water* in the boilers should be examined, tested, analyzed. This will show when too little or too much of the one or more kinds of treating reagents is being used, so that proper corrective action can be taken. This will furnish a safe guide. If one bases quantities of reagents on analyses of feed water, in ninety-nine cases out of a hundred he will be fooling himself, as he might do also by watching the feed water after the reagents are in the water but before the water is in the boilers. It is the *concentrated water in the boilers* which must be watched.

Power plants naturally differ enormously in the variable factors entering the water treatment problem. Electric railway power plants have a proverbially variable load. Most of them are now steam turbine stations and most steam turbines work with surface condensers. If the condenser circulating water is in any way bad the tubes will leak and contaminate the hot-well water. The sodium chloride content of the contaminated hot-well water again furnishes the control guidance.

Make-Up and Circulating Water Must Be Analyzed Also. Below a certain limit of salinity the hot-well water is good for boiler feeding; above a certain limit it is unsuitable. The limit of salinity above which the contaminated hot-well water is no longer acceptable as feed water depends upon the quality and cost of the make-up water. If make-up water is free, for instance, the standard set for comparative freedom of hot-well water from condenser leakage contamination should be very rigorous, provided that the make-up water is of good quality and the condenser circulating water is of poor quality. It comes

down ultimately to the writing of an equation properly relating the important and somewhat numerous terms.

Satisfactory boiler feed water at the minimum cost is the desideratum. It is the corrosive, scale-forming, and priming properties of the waters which are to be evaluated, not merely the salinity values. Thus analyses in some form of condenser circulating and make-up water are required. Upon such analyses the suitable working standards are calculated. Then salinity determinations alone suffice to dictate the admission of hot-well water to the feed lines or its rejection.

The hot-wells of the various condensers in a plant have to be dealt with upon an individual basis. In most modern stations the number of generating units is not great. Therefore if the hot-well water from any one of them becomes unduly contaminated by condenser-tube leakage and consequently the hot-well water is to be rejected it follows that a large proportion of additional make-up water needs to be immediately admitted to the feed lines. On the other hand the water from any individual hot-well may be so contaminated as to make it in itself unsuitable for boiler feed water and yet when it has added to it the water from other condensers which at the time have only slight leakage the resulting mixture may be of entirely satisfactory quality.

Sometimes Tests at Very Short Intervals Are Needed. The practical way of handling this is, of course, to have one limit for individual condenser hot-well water and another and stricter limit for the salinity of the general mixture of feed water about to enter the feed lines. If the circulating water is highly corrosive and therefore serious condenser tube leakage is imminent in any condenser at any time, it becomes necessary to make routine tests of the salinity of individual condenser hot-well water at short intervals, let us say at one hour intervals. Likewise it is necessary to make salinity tests of the general mixture of water about to enter the feed lines at the same or even shorter intervals.

A very excellent way of maintaining proper standard of feed water salinity is to make the determinations on the general mixture of feed water at quite short intervals and, whenever excess above the standard is found, immediately to make tests of all the individual condenser hot wells which are operating, rejecting

the water of the condenser which has the highest salinity regardless of what the salinity may be. While this is advantageous it necessitates *quantitative* determinations of the individual condenser hot-well salinities, whereas determinations which merely show whether salinity of a water is above or below the set standard are merely *qualitative* and therefore simpler to make. It is possible to arrange both sorts of tests so that the manipulation will be so simple that it can be readily performed by engineers entirely untrained in chemistry. In fact such simplicity is quite essential for practical station operation.

Feed Water Softeners Have Their Place. After the question of what hot-well water to accept for feed water and what to reject has been settled the problems of the general feed water treatment come up for solution. In those plants where surface condensers are used and yet the use of hot-well water is a matter troublesome even though immensely worth while financially the purification of the feed water mixture by a softening system is hardly feasible and, further, it is hardly necessary. It is such plants which in the main I am discussing. Occasionally where the make-up water is quite bad but the circulating water is fairly good, and therefore does little in the way of contaminating the hot-well water, a softening system is used to bring up the quality of the make-up water. In these cases the softening system may be of reasonable size and cost. But a softening system to handle the entire feed water of a power plant, whether the plant is using no hot-well water or all the hot-well water possible, is a proposition formidable in first cost and liable to prove disappointing in results. Such systems have substantially no representation in American practice. If the water which such a softener would be able to handle were very bad the results would almost certainly be disappointing, and if the water were not very bad the softener would be unnecessary anyway.

Although as has been shown, a water softener is limited in its scope, and although boilers are supposed to generate steam and not to serve incidentally as chemical reagent tanks, chemical water treatment of the feed water of the representative modern power plant is necessary. Further, it may be unequivocally stated that to permit the boilers to serve incidentally as reaction tanks, provided there is proper control, is far better

than to allow scale to accumulate and acidity to corrode. If scale does accumulate and acidity does corrode, the boilers are making reaction tanks of themselves anyway.

If boilers need chemicals, what chemicals do they need? The essential chemical is a soluble carbonate or a soluble hydrate, or both. A cheap soluble carbonate is sodium carbonate, that is, soda ash. A cheap hydrate is lime, but for boiler internal use it is unsatisfactory in that it ultimately increases the suspended solid matter in the boiler. A soluble hydrate free from this disadvantage is sodium hydrate, that is, caustic soda. It costs more than lime, but its cost is not prohibitive. As a basis of judgment for the treatment needed, whether full qualitative analyses are made or not, the fundamental requisite is knowledge of the hardness and the alkalinity of the feed water. Hardness should be determined by the soap test and alkalinity by the use of two indicators, methyl orange and phenolthalene. The results of these tests will determine whether soda ash will be sufficient or whether caustic soda should be used to supplement it.

Any calculations which are made of the quantities to be used should be regarded as merely tentative. The treatment should be started and the concentrated water in the boilers should be tested for hardness (by the soap test), and alkalinity (by the methyl orange and phenolthalene tests). The latter quality, by the way, is sometimes called the "causticity." If the hardness does not come down to very low values it is evident that insufficient treatment is being given. If the alkalinity to methyl orange does not numerically exceed the hardness, calcium sulphate is present and hard scale is forming. The soda ash should then be increased until the alkalinity to methyl orange does exceed the hardness. If the alkalinity to methyl orange accumulates to high values and at the same time the hardness comes down to very low values, as for instance two parts per 100,000 parts of water, the amount of soda ash should be decreased.

"Hardness" May Be Temporary or Permanent. The use of caustic soda is to prevent corrosion. If the feed water has high temporary hardness (that is if it contains bicarbonates of calcium and magnesium) and low permanent hardness (due to calcium sulphate) the use of caustic soda alone or supplement-

ing soda ash may be necessary. It should be borne in mind, however, that soda ash becomes partially converted to caustic soda under the conditions of temperature and pressure in the boilers. In other words, the tests made on the concentrated water in the boilers will show the presence of caustic soda even though soda ash may be the sole treating agent put into the feed water. Therefore in many cases the supplementary use of caustic soda is not necessary.

In turbine stations which have good circulating water and, therefore, but little tendency to hot-well water contamination through tube leakage, it is well so to regulate the feed water treatment as to prevent undue accumulation of caustic soda in the concentrated boiler water. It should be present in no greater quantity than is the sodium sulphate resulting from the elimination of hard scale-forming matter by the soda ash acting in the feed water to convert calcium sulphate to calcium carbonate.

In the above discussion the technique of water tests has not been gone into. All but one of the tests mentioned are simple, and that one is by no means difficult. The salt test and the hardness and alkalinity tests to methyl orange and phenolthalene are so very simple that any one unacquainted with chemistry can readily be taught to make them. It is unnecessary to describe them here and to show how they can be performed with least manipulation. After all, in my opinion, the main thing about power plant water treatment is its philosophy, not its technique.

CHAPTER X

GETTING MORE ENERGY OUT OF COAL IN THE POWER PLANT

The cost of coal is so great an item in the total operating cost of producing electrical energy at the switchboard of a power plant that its efficient use effects a tremendous saving, while its inefficient, negligent use cuts down dividend rates not by fractions but by integers. This cost varies from about 55 per cent in average localities during normal times to as much as 85 per cent in districts somewhat remote from mines in these days of coal scarcity and deteriorated quality.

As mentioned in Chapter IX, which deals with water in steam-driven electric power plant operation, the finished product in the power plant is kinetic energy in electrical form, while the fundamental raw material, using the term "material" in a rhetorical sense only, is the potential heat energy of the coal. The coal itself as an actual material substance involves problems so numerous and difficult to handle that broad technical knowledge is needed in the boiler room for their solution. It is here that men properly equipped can do most to make the whole plant most highly efficient and produce a saving that will show to advantage in the report of power cost.

Excessive Combustible in the Ash Is Reprehensible. The chief problem with coal is to burn it. This is the engineer's problem, and it is a difficult one, although the purchasing agent may think just now that his problem is still more difficult. A lot of coal which enters the power plant never does get burned. This fact has led many power plant operators to make the determination of combustible in the refuse a routine procedure. Probably many operators do not realize how great a loss can be occasioned by allowing refuse unduly rich in combustible to leave the plant. When the percentage of true ash in the coal is high the danger is particularly great.

Omitting refinements the approximate formula for the loss in the combustible, expressed as a decimal fraction, is:

$$Loss = \frac{(f + y)xy}{f(1 - x)}$$

Where

f = fixed carbon in coal
y = true ash in coal
x = combustible in refuse, all in per cent.

The loss may be expressed as a percentage thus:

$$Loss = \frac{(f + y)xy}{f(100 - x)}$$

A still simpler formula, if the fixed carbon is not known but if data are available as to the combustible in the refuse and the ash in the coal, is:

$$Loss = \frac{xy}{(1 - x)(1 - y)}$$

Or, in per cent,

$$Loss = \frac{100xy}{(100 - x)(100 - y)}$$

For example, if the fixed carbon is 76 per cent, the true ash is 6 per cent and the combustible in the refuse is 15 per cent, then the power plant loss is 1.1 per cent. Again, if the fixed carbon is 62 per cent and the true ash in the coal is high, say 18 per cent, while the combustible in the refuse is 30 per cent, the power plant loss is 9.9 per cent.

To avoid large losses of this kind the fires must be well burned down before cleaning, or dumping, if they are stoker fires. Such burning down is not a hardship to the fireman, and only adequate and tactful supervision is required to bring it about. Such burning down does not need to have charged against it a period of undesirably low steaming rate, for fires while being burned down are capable of making steam actively.

Clinkers Do Not Necessarily Mean Low Efficiency. The subject of the clinker in the refuse is of considerable interest in this connection. Where there is much clinker there is apt to be very little combustible. The writer noticed this some years ago

aud called attention to it in a letter written to the editors of *Power*, in September, 1905. Some time later he was interested to find reference to the letter, with confirmation of the relationship mentioned, in Bulletin No. 325 of the United States Geological Survey.

When clinker forms with any freedom it is obvious that combustion is occurring at high temperature. A temperature high enough to melt ash does not let much carbon go unburned. Of course, no one is desirous of encouraging the formation of clinker with its attendant troubles, but there is at least some consolation in the fact that when it does form the refuse losses due to the presence of combustible are small.

The nature of the true ash primarily determines the extent of clinkering. The main point seems to be that burning all but the last bit of carbon involves the burning of some carbon which is surrounded by great quantities of ash. For this high temperature is required, and at this high temperature at least some of the ash will fuse or melt.

Some Lessons from Domestic Fuel Consumption. On the general subject of combustible in the refuse of the power plant it is interesting to turn for a moment to that of the domestic use of coal in house heaters. Here we know that the use of the rotary ash sifter has done wonders in cutting down coal consumption. Mainly, no doubt, this has come about through making the rejected ash practically true ash almost in powdered form. Another saving perhaps is through the more complete burning of the volatile matter of the coal when each charge of green coal is covered with a layer of sifted cinders.

An engineer in a recent letter to *Power* stated that last year 8 tons of coal had been burned in his heater with no sifting of ashes, while during the current year, up to the time of writing, less than 6 tons had been burned and he expected that the season's consumption would be but 6½ tons. This letter was called forth by an editorial in the same paper dealing not with ashes from house heaters rich in combustible but those from many private plants in large cities. The central stations, under present conditions, have patriotism as well as fuel economy to consider.

Buying Coal According to Specifications. On the subject of coal specifications not much need be said in these days nor apparently for some time to come on account of the general fuel

situation. When, however, specifications were more useful than at present, in most cases it was the heating value of the coal which was considered the most important active control factor in business dealings between coal consumer and coal dealer. Sometimes, however, the ash and volatile matter were specified, with bonus and penalty clauses included.

The determination of heating value by means of a bomb calorimeter is now quite general practice, and where the coal is received in barges and, therefore, in units of hundreds of tons, a determination of the heat content of every barge load is frequently undertaken. The trouble and cost are looked upon as worth while even if the results are only useful for purpose of record. Where such record is available there is no doubt that extensive use is made of it in that operation known commonly as "registering a kick."

It Is Often Important to Know the Ash Fusion Temperature. Along with the growing practice of making calometric determinations of coal there are many plants which also make frequent measurements of the actual fusion temperature of the ash in the coal. This is especially true in plants having large installations of underfeed stokers, for such stokers inherently operate with high furnace temperatures. It might perhaps be more accurate to say that they operate inherently with zones of very high temperature in the fuel beds and particularly at high ratings. For this reason the ash fuses, and there is trouble with the furnace walls unless the ash of the coal has decidedly high fusion temperature.

To justify the expense of laboratory work for the measurement of fusion temperature of ash in coal shipments, etc., there must be furnished an opportunity to prevent damage by ash with low fusion temperature. This is especially true where such coal is to be kept out of underfeed stokers. It is always somewhat difficult to arrange this, for it involves a laboratory equipped and manned on a scale making possible the putting through of tests with a rush. The writer was once told by a man in considerable authority in a large plant that the men in his plant could tell how the cones of ash were going to act in the high-temperature laboratory furnace by the extent to which the coal had clinkered on the underfeed stokers. This is surely "getting the cart before the horse."

Ultimate Analyses of Coal Are Not Necessary. So far as the analysis of coal goes it may be said that no plant makes ultimate analyses. Proximate analysis is relied upon entirely. For the purpose of registering effective complaints such analysis is greatly superior to the mere determination of heating value. It furnishes ammunition for campaigns of complaint about the amount of volatile matter and a corresponding tendency to produce smoky flue gases, about the heating value, also, because the determination of ash, volatile matter and corresponding fixed carbon permits very close calculations of heating values. But the power plant man cannot kick about the moisture, for the coal man will always say that "it rained."

Just a word more about the heating value of coal. This is obtained with great accuracy in a bomb calorimeter or approximately by calculation from the result of proximate analysis, and whether or not many of the data are looked upon as worth while, anyway, just as a matter of record, it is positively essential to know the heating value of the coal so that the thermal efficiency of the station can be calculated. Every engineer nowadays wants to calculate the thermal efficiency of his plant. It is impossible otherwise for him to know what he is doing with his plant. My advice, therefore, to the power plant man who lacks a calorimeter, crucibles, gas burners and oxygen tanks is to make out a requisition for these necessaries. The boss will surely sign it.

What About the Poor-Quality Coal That We Are Getting Now? The present crisis in the coal industry has produced a great deal of irregularity in the quality of coal and it has deteriorated noticeably. A great deal has been written to explain this situation and to outline the steps that the government might take to restore conditions more nearly to normal. Lately the federal Fuel Administrator has issued regulations for the purpose of improving conditions. Power plant engineers have complained bitterly of the quality of coal which they are receiving.

Undoubtedly in many instances coal has been supplied which, because of its poor quality, has produced an alarming rise in maintenance cost of furnace equipment. In some cases, however, the poor quality has meant little more than a serious lowering of heating value. It seems to me sometimes that users of high-quality coal grow to be a pampered element in our popu-

lation. Barring coal of low heating value which happens also to be characterized by low fusing temperature of ash, it seems to me to be an open question whether something other than very high-quality coal is not the most suitable for power-plant service. Of course, very high-quality coal is not used in many large power plants. There is not, in truth, enough of it to go around. Even in normal times the steamship trade takes most of this coal and it is proper that it should do so. Aside from the steamship trade really good coal should be looked upon as a luxury which only the rich among corporations can afford.

In power-plant service the dictum is sometimes heard: "The cheapest coal to buy is the cheapest coal to burn," but this is a very unsafe dictum if taken without reservation. It is, however, one which bears examination in concrete cases, but such examination has a reliable basis only in tests of the evaporating quality of the fuel. These tests should be comprehensive and planned definitely to cover a range of steaming rates wide enough to reveal possibilities of economical use of the coal under conditions of station operation possibly differing somewhat from the normal.

Such conditions may be entirely satisfactory and may, in fact, resemble those which have long been used elsewhere.

The great problem with coal, as stated before, is to burn it efficiently. We shall assume that it has been properly selected; that it is of quality not too good for the circumstances, and not too cheap, if cheapness is accompanied by the presence of clinkering qualities caused by ash with low fusing temperature. Further, we shall assume that proper supervision has been provided and good firing methods ingrained in the fireman so as to insure no large loss of combustible through the ashpits. The next question is how the heat loss up the stack is to be kept moderate or low. This is a very important question. Many people are willing to step forward to tell us how to answer it, or to write articles about it. Engineering societies spend unhappy evenings discussing it. Makers of instruments are anxious to provide equipment designed to make the solution of the problem easy. Personally I do not desire to be one of the general company of wiseacres along this line.

There was a time when I was much impressed with magazine articles demonstrating so easily the enormous heat losses through

the stacks occasioned by decreasing values of CO_2 (on the false basis that the flue temperature remained unchanged). The savings to be made by high CO_2 were heralded so widely that the power-plant operator who had escaped being greatly impressed thereby was surely a "wayfaring man and a fool." I was, however, much depressed by the absence of sharply defined counsel on how to get high CO_2. The articles simply said when the CO_2 percentage is high the excess air is low.

A Practical Demonstration in Efficient Boiler Operation. I found out later how to manipulate the furnaces and drafts so as to produce a high percentage of CO_2, but along with this knowledge came the conviction that such manipulation is not worth while. The following experience contributed to this conclusion.

I was conducting a series of tests on a water-tube boiler fired by an overfeed stoker using semi-bituminous coal low in ash and of a quality considered particularly suited to the station conditions. This coal had long been used in the station and on the stoker in question. There had been conferences, tests and what not for a long time in regard to the operation of the equipment. The stoker manufacturer sent an expert operator to do his bit.

The tests were made long after the stokers had been installed. They included three series of tests exactly alike except that during each of the series a different man was in charge. Each man operated with unimpeded control except in one particular, namely, that the flue draft was maintained during each eight-hour test by a man who watched constantly a draft gage connected to the flue nozzle on the boiler side of the damper and manipulated the damper so as to maintain constant draft.

Each series consisted of five tests of eight hours each, and flue drafts of 0.36 in., 0.40 in., 0.44 in., 0.48 in. and 0.52 in. water column were used. Each man operated the stoker with these drafts, there being fifteen tests in all. Each man manipulated the stoker mechanism to suit himself, adjusting the rates of coal feed and grate movement, deciding when and how to dump ashes, etc.

In every way he did what he pleased except that the draft at the flue nozzle was established for him. The coal and water were weighed, the gas was analyzed for his inspection, tempera-

ture and pressure measurements were made and displayed to his view if he cared to look at them.

High Efficiency Accompanies Low Coal Consumption. As previously stated, one man was an expert sent by the stoker manufacturer. Another was a head fireman who ordinarily did not run stokers but graduated years before and put in his time eight hours a day showing others how to do it. The third man was a good stoker operator but of no particular skill, and he was quite illiterate judged by any standards current among combustion experts. He could barely speak the English language.

Now I am not going to say that the last man beat the other two. It is not so easy as all that. At every one of the five values of flue draft the highest economy of evaporation, the highest over-all efficiency by far, was attained by the man who at each particular value of flue draft used the least coal per hour. At one draft value it was one man, at another another man. Each of the three men secured honors in the tests, but how they were divided I do not remember. Always, however, the man who with a given flue draft used less coal than the other two at the same draft was the man who won out, and by a large margin.

This conclusion that the least coal at a given flue draft corresponded to the best operation is worthy of careful thought. Does it mean the use of a thin fire? Does it argue for considerable excess air? I leave these questions to the reader as a profitable subject for his reflection. The problem is obviously a vital one if fuel consumption is to be fully controlled.

CHAPTER XI

KEEPING POWER PLANT OIL IN GOOD CONDITION

The following discussion of oil in steam turbine power stations aims to bring forward for examination some of the aspects of turbine lubrication which among many engineers to-day are regarded as problematical. My hope is that a certain amount of discussion may result which, for myself as for others, will clear up in a measure some of the points on which many of us are seeking further light.

Oil Does Deteriorate in Service. It has become very common of late in the literature of turbine lubrication to find the frankest sort of reference to the formation of oxidation products in turbine oil which has circulated more or less continuously for a considerable time, whatever may be the particular type of circulation and oil filtration.

This frank reference to oil disintegration in continued service is rather recent. Not long ago the writer met oil salesmen who professed never even to have heard of such a thing. While confessing themselves entirely mystified as to the nature and cause of such action these salesmen were yet able to express entire confidence that their own oil would not disintegrate. And it is only a few years ago that some turbine designers were ready to let it appear that they at least looked a little askance at some oils and more favorably on others. Now the basis of their likes and dislikes appears to be that in one plant conditions more favorable to growth of oxidation or polymerization products threw the onus of blame upon the oil in use, rather than upon the local plant-operating conditions.

Of a truth all oils in continuous turbine lubrication service will form such oxidation products. What the operating engineers want to know are the facts regarding the specific liability of a given oil so to deteriorate, and the plant equipment and operating features which stimulate or alleviate the inherent tendency of the oil to further such growth within itself.

Oils Become Acid as They Deteriorate. The oxidation or polymerization products always produce an acid condition in the oil, in fact such products are measured quantitatively in terms of some relatively simple organic acid. Perhaps the acid most commonly employed for this reference purpose is oleic acid. And yet oil has sometimes been condemned as improperly refined because after long service it had this distinct acid reaction.

Naturally when the acidity of the oil in service has reached considerable proportions there is danger that the oil will do what any acid circulating in a turbine would do, namely, cause corrosion. Before discussing this matter, however, it is important to mention an accompaniment of this acidity, that is the formation of "muck." One of the live questions of to-day is as to the extent to which the oxidation products and the muck are one and the same thing.

"Muck" Is the Cause of Much Trouble in Oil. In many turbine plants the mere creation of such acidity as that described above seems immediately to cause that most common of chemical actions, the attack of acid upon metal with the production of salts. These salts, which may exist in a turbine oiling system, have quite different properties with respect to different metals. For instance, when these acid products act upon zinc the resulting precipitate seems to be particularly voluminous.

To whatever extent, then, oxidation products essentially form muck the impurities in the oil are greatly increased when it comes into contact with metallic zinc, as for example in galvanized oil piping. Such piping should, therefore, not be used in turbine oil circulating systems.

In any case the muck itself is a detriment to lubrication. If the plant engineers are not watchful or are unsuspicious of the possible presence of muck, actual trouble may result. Some very large turbines in important power plants have had not only "near shutdowns" but have suffered the complete burning out of bearings from this cause. Such accidents, happily, rarely occur more than once.

What Shall Be Done with Run-Down Oil? Now as to remedies, it is wise not to become discouraged too easily. The writer was informed some time ago that in a very large power station where bearing trouble had been experienced the engi-

neers finally realized that unavoidable leakage and evaporation are not the only causes of oil consumption. They established an old-age limit for oil. When the oil reaches the age limit it is simply relieved from further duty, and the burden put upon new, fresh oil.

Such extreme procedure seems to the writer hardly to be justifiable. I believe that there are two lines of attack for the problem. In the first place, one of the most important facts connected with the whole subject of oil muck and its elimination from a turbine oil circulating system seems to be that certain features of such a system which tend most effectively to rid the oil of water have a most perverse effect in hindering the elimination of muck from the system.

The subject of water in turbine oil has received much attention of late years. Among the features of importance are the property of the oil by which it forms an emulsion with water, and the relative ease or difficulty with which an emulsion once formed may be broken up and the water separated from the oil. The United States Bureau of Standards has come forward with notable contributions to the subject. In the equipment provided in power plants for cleaning and filtering oil it is very common to find apparatus for heating the oil about to be filtered, thereby rendering the separation of water much more rapid and complete.

Temperature Is an Essential Element in the Precipitation Problem. Unfortunately the deliberate heating of turbine oil in a filtering system interferes with the extremely important function of filtering, barring of course the separation of mere dirt and metallic particles. The acid oxidation products are in fact prevented from being separated by such heating. These products have a solubility in the oil which varies with the oil temperature. At high temperature the muck goes into solution, and as the oil cools the oxidation products are precipitated out as muck.

This variable solubility with changing temperature is the feature which perhaps more than any other makes the oxidation effect a very serious problem in turbine lubrication. While the oil is circulating in the bearings it becomes hot, and the high temperature favors the formation of the oxidation prod-

ucts with the accompanying increasing acidity. So long as the oil remains hot the oxidation products largely remain in solution.

Muck Interferes with the Operation of the Cooler. In the oil circulating system the oil which is bearing the lubrication burden at one moment is a moment later relieved and at rest in the oil cooler. As it is cooled, however, the acid oxidation products are precipitated. They settle out, fouling the cooling surfaces and reducing the heat transmission through the coils or tubes to the cooling water. Now if the oil-cooling process is interfered with, the oil returns to the bearings at a temperature already high, and it becomes hotter there than it otherwise would.

High temperature is without doubt an important factor in the formation of oxidation products, and consequently more muck is precipitated in the cooler. There is thus a vicious cycle of operations. It would be much worse but for the fact that as the oil heats its viscosity decreases and the bearing friction is thus reduced. Therefore the power loss in the bearings is reduced, since this loss in a bearing is proportional to the product of friction force and speed. With reduction of power loss in the bearings the oil is heated at a lower rate. The temperature reached is, however, much higher than it would be if the heat transmission surfaces in the cooler were clean.

The precipitation of oxidation products in the cooler and their separation from the oil after precipitation are by no means so complete as to render the oil leaving the cooler for the bearings practically free from them. These products contaminate the oil entering the bearings and beyond question increase its coefficient of friction. They are, however, taken up again into solution as the oil heats in the bearings, so that there is at least some compensation.

The Oil Reservoir Pockets Are Favorite Retreats for Muck. Nor does all of the precipitation of muck occur in the cooler. Much of it occurs in the pockets of the oil reservoir space, the temperature there being much lower than that of the bearings themselves. In these pockets the precipitate has the best chance of all to settle out, and when considerable time elapses between cleanings the extent and nature of the deposits are sometimes

surprising. They are sometimes in the form of soft muck, often gummy and at times even approaching the consistency of pitch.

There is undoubtedly some danger that with such accumulations the distribution of oil to all parts of the bearings needing it may be interfered with. On the other hand, it is easy to exaggerate this danger. In the first place the high temperature of the oil in the bearings keeps the oxidation products very largely in solution where the oil is doing actual lubrication service. Then again the precipitation of these products, where such does occur, is small in relation to the quantity of oil in which it occurs, while the particles of solid matter come down in a state of very fine sub-division. Accumulations occur, therefore, generally only where circulation is very slow and where the oil is losing heat by radiation and conduction.

"Rejuvenating" Oil After Partial Disintegration. The very finely subdivided state of the precipitated matter must be kept in mind in devising means for dealing with the whole matter. As has already been mentioned, the oxidation products, due to their acid nature, may produce salts of metals which are themselves insoluble. These as solids have much to do in determining the quantity and form of the so-called muck. This is notably the case with the zinc salts which are apt to result from the use of galvanized piping. Without zinc, however, the precipitate is far from flocculent and its separation from the oil with reduction of acidity is a problem of importance in many a power plant to-day.

Unfortunately the filtering of power station oil is done largely with apparatus developed fundamentally to meet the requirements of engine oil filtration and modified in no really important and essential features to meet the turbine oil filtration problems of to-day. This lack of adaptation is indeed not strange if I am correct in arguing that only recently has the real nature of turbine oil filtration problems been correctly understood.

Turbine Oil Cannot Be Treated Like Engine Oil. There are two items in the problem which did not exist when the principles and practice of engine oil filtration were developed. The oil in engine circulating systems was contaminated by water and dirt. The water did not generally emulsify with the oil,

or at any rate the emulsions were not particularly tenacious. The separation of the water from the oil was rather easy. The heating coils frequently used in engine oil filters separated the water from the oil even in difficult cases. The separation of dirt from engine oil was, of course, a filtration problem of the simplest sort. So simple was it that many an engine oil filter was merely a crudely improvised collection of canvas bags, with not always the closest attention to eliminating leakage paths.

The separation of water from turbine oil was early recognized as of far greater difficulty. Persistent emulsions were not uncommon and the characteristic behavior of individual turbine oils in this respect began to be closely studied. Much was done in the quantitative measurement of demulsibility, and in this the United States Bureau of Standards took a leading part.

As previously mentioned the two essentials of turbine oil "rejuvenation" for continued lubrication service are (1) the solubility of the acid oxidation products in hot oil, and (2) the finely subdivided nature of these products when precipitated in cool oil. It follows that the filters must not be set to filtering hot oil. It may, however, be necessary to use heat to break up the water-oil emulsions, although even this necessity is questionable. It is quite essential that effective cooling shall be provided previous to filtration.

It may be well to mention in passing that the entire oil contents of a turbine, which is taken out of service for the purpose of cleaning and renewing its oil supply, should be run out of the reservoir as soon as the turbine has come to a standstill, thus insuring the minimum precipitation in the pockets or in the oil grooves and the maximum quantity of acid oxidation products carried out of the turbine in solution in the warm oil. If this is not done the oil will cool in the idle turbine and a certain amount of precipitation will occur.

The Filter Press Might Be Used with Turbine Oil. When provision has been made for cooling the oil in the proper place and thereby bringing the precipitation under intelligent control, there still remains the task of removing the fine precipitate, which cannot be done with bag filters. One hope in this direction is the filter press. For many years this device has been successfully used in many processes of manufacture and refining. Its use in power plants has been practically unknown until

very recently. So far as the writer knows, F. R. McLean was the first to propose it for the clarification of turbine oil from precipitated acid oxidation products. For this purpose it is very attractive. It is not expensive, and is very compact. It has great filtering capacity and flexibility. The effectiveness of its filtering may be made anything that is desired. In the numerous manufacturing and refining processes in which it has long been used its place is quite unchallenged. Its future in steam turbine power plant service seems very bright.

The Whole Matter in a Nutshell. Summing up this whole matter, it may be said that the problems of turbine lubrication are problems of the durability of the lubricant. Water emulsions do no permanent harm to the oil but they are highly objectionable until broken up. The tendency of oils to emulsify and the measurement of their demulsibility have been studied extensively. The tendency of turbine oils to form oxidation products in service has been studied also, perhaps most actively by the oil men themselves. The progress so far made is uncertain and the field is unquestionably very difficult. Probably the oil men have learned more than they have told the rest of us. Some progress is also being made in tests which might be called "accelerated acid oxidation product test," but standardization of such tests seems so far a goal quite unapproached.

CHAPTER XII

WHAT IS THE CURE FOR CONDENSER TUBE CORROSION?

In the modern power plant, operated with surface condensers, corrosion of the innumerable and tiny tubes which make up the "internal economy" of the condensing apparatus has long been the bane of the operator's existence. There is daylight ahead, however, in this matter for, like most of the problems of these days of increasing use of research methods, the condenser tube problem promises a real solution at no very distant date.

For many years the development of ideas concerning tube corrosion was very slow, but recently it has been greatly accelerated. The earlier condition was due partly to the fact that important as the matter seems to power house operators, the corrosion of condenser tubes is only a part of the general corrosion trouble. In the whole field it is of relatively minor commercial significance. If, however, iron and steel corrosion are excluded, as well as that of the alloys used in engineering structures, the waste of money occasioned by the short life of condenser tubes becomes relatively very important. In fact, it is so large as to be exceeded by few other wastes among applications of alloys in which the corrosive influence is a factor. It is worthy of careful study.

The whole corrosion difficulty has been attacked with great vigor in recent years, both theoretically and experimentally. Theories have been extensively modified and, as is generally the case where this occurs, progress in experimental lines has kept pace with the theory.

Electrolysis Has Been Blamed for a Great Deal of the Corrosion. An important fact in this connection is that but a few years back many of the large steam turbine condensers were equipped with Muntz metal tubes. Another is that in the early days it was quite commonly supposed that much condenser tube

corrosion was caused by electrolysis from the return current of electric railway circuits.

Expensive experimental installations were made in a few cases for the purpose of electrically insulating the condensers. Another line of experiment consisted in coupling a special motor-generator set to the condenser so that electric current of considerable magnitude would flow from the condenser shell to the tubes. This idea has been very persistently advocated in England, where it has produced the "Cumberland system" of condenser protection.

Another, and fairly recent, theory of corrosion is that electrolysis may occur without the assistance of electric currents from outside. The idea is rather that corrosion of apparently homogeneous metals occurs through the operation of tiny local electric circuits. These may be almost molecular in dimensions. They are produced by non-uniformity in the metallic structure, or perhaps it would be more accurate to say in the metallic micro-structure to indicate the diminutive character of the action.

Muntz Metal Is Very Susceptible to Salt Water Attack. It is well known that Muntz metal is attacked quite vigorously by salt water. This metal contains two constituents known as "alpha" brass and "beta" brass. Under microscope these two constituents can be easily distinguished. The "alpha" constituent is a solid solution of zinc in copper which may contain, under circumstances dependent upon heat treatment, as much as 37 per cent zinc, and which, when less than 30 per cent zinc is in the brass, is the exclusive solid solution present. It is a comparatively soft and very ductile body. The "beta" constituent is a solid solution of zinc in copper which is always present when brass contains more than 37 per cent zinc. This constituent is much harder and stronger than the "alpha" constituent but it is at the same time much less ductile.

Each pair of these constituents can act as electrodes in local electric circuits when en electrolyte is present—for example, salty circulating water. These electrodes, that is the "alpha" and "beta" constituents, have very considerable inherent potential difference. There can scarcely be any doubt that this circumstance explains, for the most part, the special susceptibility of Muntz metal tubes to corrosion by salt water. This

conclusion will, I believe, be supported by all who have used such tubes with salty circulating water, or certainly it will be supported by those who, having used them, have changed to Admiralty metal tubes.

Admiralty metal contains 70 per cent of copper, 29 per cent of zinc and 1 per cent of tin, while Muntz metal contains 60 per cent of copper and 40 per cent of zinc.

Electrolysis Theory Applies with Admiralty Metal Also. Any brass having as much copper as Admiralty metal consists of a single solid solution of zinc in copper, that is, "alpha" brass. This is true of all brass alloys still more rich in copper.

While the electrolytic theory of corrosion still serves to explain, or at least helps to explain, the corrosion of Admiralty metal tubes and other "alpha" brass alloy tubes, it is evident that the homogeneity of the crystals of the single "alpha" solid solution is much greater than in the case of Muntz metal. The theory requires the presence of tiny electric currents due to lack of uniformity, but obviously the potential differences are very much less in this case than those which exist between the crystals of the "alpha" and "beta" solution of brasses having copper of about 60 per cent and zinc of about 40 per cent, of which Muntz metal is an example.

The point is often made that if 70 per cent copper is so much better than 60 per cent copper, why would it not be still better to use 80 per cent or 90 per cent copper or alloys even richer in copper than this?

There are several reasons for the use of a limited percentage of copper. In the first place, copper is more expensive than zinc, therefore the cost of the tubes rises with increasing copper content.

Why Not Use Condenser Tubes of Pure Copper? Another important fact, already mentioned, is that brass containing as much as 70 per cent of copper or more consists of one rather than two solid solutions; that is, the "alpha" rather than the "alpha" and "beta" metal. It follows that once the "beta" constituent has been removed there is no further improvement to be effected by the addition of more copper.

It is true, of course, that as electrolytic corrosion goes on, it is the zinc which is dissolved and the copper which remains. The honeycombed structure which is left is very weak mechan-

ically and is broken easily by vibration. It follows, therefore, that the less zinc originally in the tubes to be dissolved, the less is the resulting weakening of the tube as it deteriorates throughout its life.

Carrying this argument to its conclusion one might ask: "If the less the zinc in the tube the longer its life, why not use an all-copper tube?" The answer to this is that the omission of the zinc would be undesirable as a manufacturing matter. It appears from the metallurgy of tube manufacture that copper oxide is produced in the making of tubes and this is very soluble in molten copper. Copper oxide in a tube is very bad. Zinc in alloying with copper takes care of the oxidizing effect.

Many engineers believe that a little zinc will perform this oxidizing service as well as a great deal and that, therefore, condenser tubes of progressively higher copper content should have correspondingly longer life up to, say, 95 per cent of copper. To offset this increasing merit would only be the corresponding higher cost.

While the above opinion seems to be quite widespread among engineers, it cannot be said as yet that the use of tubes so rich in copper has been tried long enough in a practical way firmly to establish the validity of the theory. Certainly it is not established to so great an extent as the fact that Admiralty metal tubes are superior to Muntz metal tubes for condensers with water more or less salty in character. It may be said in passing that a tube of 70-per cent copper and 30-per cent zinc composition, possessing the merit of a single solid solution, "alpha" brass, is considered less durable for salt water service than one containing a slight amount of tin, hence the popularity of the well-tried Admiralty metal. The rôle played by the tin in giving this added protection is, however, not well understood.

So far we have discussed the chemical composition of tubes as affecting their durability against corrosion, but there are other factors which have an important bearing on the subject. Some of the most important work done in this line is so recent that manufacturers have not as yet had time to provide equipment to make the fullest use of it.

Before taking up this latest work it may be well to state first that for some years engineers have felt that very important influences were at work, other than variation in chemical composi-

tion, which would account for tube deterioration. These men were convinced that not much improvement was to be secured until these factors had been identified and brought under practical control.

The investigators turned naturally to the microscope to assist them, and the character of grain structure and its relation to annealing were carefully studied. The literature of this subject is now quite extensive.

In spite of all this study, however, it did not seem possible to distinguish accurately between good tubes and poor tubes. About five years ago, however, the brass industry got a very heavy "jolt" which brought about important investigations and had far-reaching effects.

On the New York State Barge Canal work, and also earlier, on the Panama Canal work, large quantities of brass and bronze were used under conditions subjecting the material to considerable stress. These materials had been chosen under the circumstances as substitutes for steel in order to insure against corrosion. The structures in which they were used were carefully designed for the applied stresses.

In no small number of cases these materials failed, causing genuine alarm among engineers for the safety of some of the structures in which they were used. The result was a decided skepticism as to the suitability of such alloys for structural purposes. In some cases steel was substituted for the alloys.

In the investigation which followed the United States Bureau of Standards took a leading part, applying its rigorous research methods to this work. The result seems to have been very satisfactory.

What Is the Cause of "Season Cracking"? One evil to which alloys are subject, known as "season cracking," has long been widely known in the brass trade. It has seemed in some way to be connected with moisture conditions. Brass and bronze kept quite dry might be entirely free from this trouble even though long in service, whereas these alloys kept in storage and, therefore, subject to no stress at all, might give evidence of "season cracking" if subjected to moisture conditions. The failure of such alloys in service when subjected to high but carefully calculated stresses and to corrosive influences has already been commented upon.

In a general way it was known fairly accurately that "season cracking" was related to internal strains produced in manufacture and not subsequently removed. Recent investigation has clarified and amplified our knowledge of the whole subject, however, very much indeed. We now know that "season cracking" and "corrosion cracking" are one and the same. Consequently an organized effort to allow the former term to die out of use meets with no opposition.

We now know that "corrosion cracking" and initial *tensile* stress are not only associated phenomena but also that without the latter "corrosion cracking" does not occur.

Initial tensile stress, which is a cause of corrosion cracking, is bound up with the matter of electrolytic solution potential. Some of the best recent research work seems to establish definitely that this potential increases continuously with tensile stress.

The way in which corrosion cracking comes about is therefore as follows: Newly manufactured metal, say brass condenser tubing, is in a state of initial stress of such nature that the surface layers are in tension. There is always sufficient lack of homogeneity on the surface to start electrolytic corrosion if an electrolyte is present. This may be assumed to be the case when the tubes are in service in a condenser.

The early surface corrosion grooves the surface and, as it is a law of mechanics that the unit stress at the bottom of a groove is far higher than the average stress over the surrounding section, the early surface corrosion produces higher unit stresses at the bottoms of the grooves as these deepen.

We have assumed a case where the initial surface stresses are tension stresses. Therefore as the grooves deepen the electrolytic solution potentials at the bottoms of the grooves increase, and as this occurs the differences of potential between the bottoms of the grooves and the general tube surface are increased. As a consequence the electrolytic corrosion is not only maintained but accelerated.

What Are We Going to Do About It? Now as to some hope of cure for these ills. Initial compression unit stresses seem harmless—that is, they do not seem to favor corrosion cracking. The reduction of initial tension stresses from the high values,

which are often very high indeed, is obviously a cure for the evils caused by high-tension stresses.

Either one of these conditions may be deliberately brought about by a finishing operation during manufacture. Annealing after the final drawing, with the annealing temperature kept to the low figure of 400 deg. C., or thereabouts, will completely remove the internal strain. At the same time it will produce a finely grained microstructure, completely eliminating the coarse structure which results from annealing at temperatures within or above the critical range.

This very important conclusion of recent research work will doubtless in the near future be much better appreciated than it is to-day. As yet the brass works are not generally equipped with the control apparatus needed for the maintenance of such low annealing temperatures.

As a substitute, however, efforts are being made so to spring the metal after the last drawing as to change the stresses which have resulted from cold working, from tension stresses at the surface to compression stresses. This is being done with a fair degree of success in the case of brass rods, but whether it can be done with similar success in the case of seamless tubes, the writer cannot say at the moment. In this connection, however, it must be remembered that the present advance in this field is very rapid, both in research work and manufacturing.

A very pertinent question with which to close the present discussion is this: "What are some of the main features which are being embodied in progressive condenser tube specifications?" In answering this question it would be well to state that these features will undoubtedly become much more important in the near future, as they have for their purpose the securing of tubes which will stand difficult corrosion conditions with sufficient durability to cut down condenser maintenance costs. Moreover, they will tend to eliminate general power station troubles resulting from contaminated hot-well water. This is a very serious item of power station expense where circulating water is in any way bad.

Modern Condenser Tube Specifications Are Quite Comprehensive. Among the items which may well be included in these specifications are the following:

Chemical Composition: (a) Such as will exclude the "beta" solid-solution constituent. (b) Presence of small amount of tin (about 1 per cent) if condenser water is salty. (c) Limitation to very small quantities of those elements generally believed to be injurious, such as lead, iron, arsenic, cadmium.

Initial Surface Stresses: (a) Elimination of such stresses by low-temperature annealing after final drawing. (b) Creation of initial surface compression stresses after final drawing by deliberate springing as a possible substitute for (a).

Grain Size: Specification of grain size and enforcement of the specification by grain-size measurement, using one or another of the authoritatively recognized methods.

Hardness: Specification of hardness number on some recognized scale, preferably the Brinell.

CHAPTER XIII

KEEPING CONDENSER PERFORMANCE UP TO THE MARK

Economy Measured by Vacuum in Terms of Intake Water Temperature. The establishment of the relationship which exists between the highest practically obtainable turbine economy, or power plant over-all economy, and the vacuum in the top of a condenser and at the turbine exhaust nozzle, may be gotten in one way or another, dependent upon test facilities and circumstances, but that relationship which is within the reach of all is to determine the highest vacuum actually attained in terms of intake circulating water temperature. This only requires records of observations kept over a considerable period of time, and naturally the longer the better. All sorts of variable factors conspire to make most observations noticeably less excellent than the best actually attainable, so that in the direction of *poor* results the figures scatter in a haphazard manner when plotted, but in the direction of *best* results they mark out a boundary line which is both smooth in shape and rational in form.

Such a plot is shown in Fig. 24, extending over a period of only about six months and taken in a typical turbine power plant. It covers data not only from nine different turbine-condenser units, but these units happen to be divisible in the matter of design into groups of three distinct types. All three types are represented at or very near the boundary line.

It is very significant that a plot of the sort shown in Fig. 24 proves that vacuum maintenance at the top of a surface condenser becomes handicapped by the rise of circulating water entrance temperature which takes place during the summer. This is due not merely to the direct effect of the rising temperature but to secondary effects as well, which are somewhat involved but are undoubtedly connected with the rising height of

the air cloud, caused by the decreasing efficiency of air removal by the pump equipment during hot weather. To state the over-all effect briefly it may be said that any plot of the kind shown in Fig. 24 will reveal greater temperature difference between the steam temperature at the top of the condenser corresponding to saturation pressure and the entering temperature of circulating water during summer than during winter.

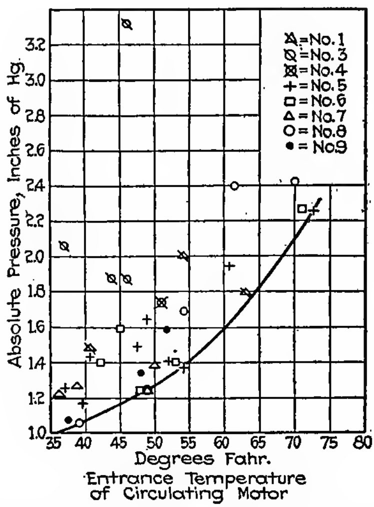


FIG. 24—VACUUM OBTAINED IN TERMS OF INTAKE CIRCULATING WATER TEMPERATURE

The Curve of Highest Possible Plant Economy Is Obtained from the Best of the Readings

After the establishment of such a standard it ought to be possible to make a strong drive after good condenser vaccum maintenance, because the operator can tell just how far he can go in condemning the indifferent performances shown by observation, regardless of the season of the year. This should make possible the drawing up in the course of perhaps another year of a new standard plot which would not only better the old one with respect to the boundary line of best performance but would be characterized also by less profuse scattering upward into the region of poor and even very poor performance. Such improvement in the standards of performance could hardly be expected to be continuous from year to year, but it ought to be the result

of this sort of intensive and scientific analysis of vacuum maintenance that the first standard established even by accumulations of very considerable data would fall short of what might in time come to be regarded as the ultimate standard.

While it would unquestionably be desirable to make a careful analysis of the vacuum maintained by each condenser every day, yet in a plant with numerous turbines it becomes a matter for decision as to whether brief observations should be made on all machines operating or whether much more extended observations should be made on two or three machines so that really detailed diagnosis of their ailments may be followed by equally detailed recommendations of the particular kinds of maintenance work necessary. The writer is inclined toward the latter view. Whatever the nature of one's inclinations, however, it comes back to the fact that detailed recommendations cannot be made unless they rest upon adequately detailed observations and analysis of observations.

Reasons for Form Suggested for Tabulating Condenser Data. Illustration of a form for observations of the detailed type is shown in Fig. 25. This form grew out of a form which merely provided for checking up condenser mercury columns, and bears distinct traces of its lineage. The items under "Condenser Performance Data," however, cover in a pretty thorough manner the kinds of data which not only suffice but are required for detailed diagnosis. The order of arrangement of the items may possibly be open to some criticism. In a general way, however, those items are listed first which are matters of direct observation, and they are followed by items which involve some calculation or which are of perhaps secondary importance, and the last item is one which, although of great importance, is quite special in the sense that it could not possibly be obtained simultaneously with the others.

The circulating water discharge temperature is put high upon the list because, while it is the circulating water intake temperature and the quantity of water circulating and the turbine load which establish the circulating water discharge temperature, it is this latter temperature which establishes directly, but in a complex manner, the steam temperature at the top of the condenser and therefore the vacuum in the turbine exhaust nozzle, and therefore the economy of the turbine under consideration.

Next come data of the rises of temperature through the several passes of the condenser, be they two or three. These data are of very great importance because it is a common thing for a most unseemly great proportion of the total rise to occur in the upper pass. This means congestion of heat absorption in the upper pass with consequent undue excess of entering steam temperature above the discharge water temperature, and meanwhile

T. D. CO., TESTING BUREAU

VACUUM MAINTENANCE AND CALIBRATION OF CONDENSER VACUUM GAUGES.

Sheet No. 1. T. B. Order........ Williamsburg Power Station

		Found Reading Inches of Hg.		Left Reading Inches of Hg.				Temp. of Cir. Water F.°		R.P.M. of Pumps	
Date	Condenser No.	Stand. Hg Column	Cond. Hg. Column	Stand. Hg. Column	Cond. Hg. Column	Barometer	Load Kw.	Intake	Disch'ge	Air	Cir-Water
						Bristol					

CONDENSER PERFORMANCE DATA

Condenser Number,			
Absolute Pressure, Inches of Hg.,			
Speed of Air Pump, R.P.M.,			
Speed of Circulating Water Pump, R.P.M.,			
Circulating Water Discharge Temperature,			
Temperature Rise of Circulating Water, Upper Sect.			
Temperature Rise of Circulating Water, Middle "			
Temperature Rise of Circulating Water, Lower "			
Load K.W.,			
Pressure on South Gland, Lb. per Sq.In.,			
Condenser Hours since Last Cleaning,			
Millions of Pounds of Circulating Water per Hour,			
Diff. Pressure across Condenser. (Ref. to Rated Water),			
Water Level Intake,			
Lost Head with Rated Qnty. of Circulating Water, Ft.,			
Excess Temperature of Steam over Discharge Water,			
Air Pressure in Air Suction Line,			
Absolute Pressure in Clsd. Suction Line of Air Pump,			

FIG. 25—FORM FOR TABULATING DETAILED CONDENSER PERFORMANCE

the large investment representing the lower part of the condenser is not earning adequate money. Great preponderance of heat absorption in the upper pass is sure evidence of improperly proportioned steam passageways through the condenser, or the presence of a cloud of air which has risen to rather high level in the condenser. This latter, if it exists, is due to large air leakage into the condenser or poor efficiency of air removal, or both.

It is the business of the diagnostician to clear up contingent possibilities and become specific. If a condenser has improperly proportioned steam passageways, presumably the diagnostician knows it by general acquaintance with steam condenser technical literature of recent years, and calls it to the attention of those in authority who do not know it, if there are any such, and plans are made to provide more adequate steam spaces by permanently removing tubes. If large air leakage into the condenser exists, quantitative measurement of the leakage with an air bell will reveal it. Rotary pumps of the jet type, as distinguished from reciprocating dry-vacuum pumps, do not admit of the use of an air bell. Very good work in such circumstances can be done by applying Dalton's law to simultaneous observations of temperature and pressure in the air suction line. Provision for the result of such measurements is made on the line next to the last of the illustrated form, Fig. 25. It should be noted that if measurements in the air section line are made with the purpose of applying Dalton's law, refinement of measurement should be attempted because rotary pumps of the jet type frequently have quite large displacement, with the result that if small or moderate quantities of air are leaking into a condenser the air in the act of withdrawal may be diffused through such a very great volume of very low pressure steam as to make the detection of the presence of the air, and much more its quantitative measurement, a matter of difficulty. There is the consolation, however, that if air is being withdrawn in large quantity the detection of its presence in the air suction line will not be difficult. It should be remarked also that the Dalton law method of quantitative measurement of air removal from a condenser is just as applicable to dry-vacuum pump installations as to the others, subject only to the difficulties incurred in pressure measurements in pipe lines supplying any sort of reciprocating pumps.

Other Possible Faults to Which the Form Calls Attention. It may suffice to take up somewhat briefly a number of the remaining items of importance appearing in the form shown in Fig. 25. Where water-sealed glands serve to prevent air from entering the turbine the pressure of water maintained on the gland supply lines by normal pumping action indicates normal or abnormal functioning of the glands with respect to water

consumption. If, for instance, the water consumption becomes abnormally large the water pressure will fall and the air-sealing

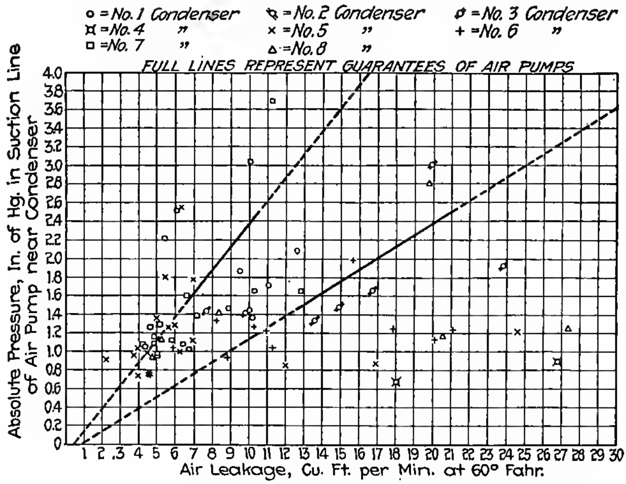


FIG. 26—CHART FOR COMPARISON OF ACTUAL WITH GUARANTEED AIR LEAKAGE

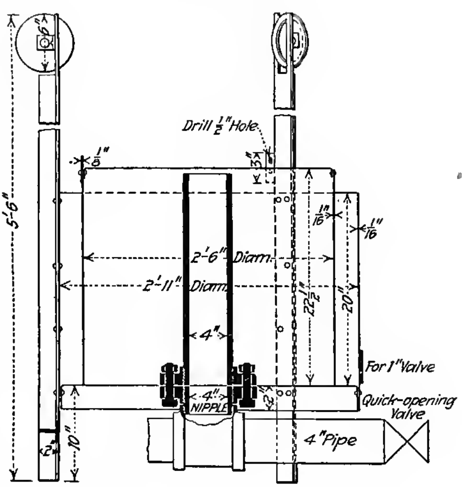


FIG. 27—AIR BELL FOR MEASURING AIR LEAKAGE

efficacy of the gland will be interfered with, with consequent high air leakage and low condenser vacuum.

The hours that a condenser has run since its last cleaning may affect the vacuum in two ways—it may account for a falling

away from the normal quantity of circulating water by reason of trash accumulations actually obstructing the flow, and it may interfere with the transmission of heat through the tubes to the water by reason of the heat insulating effects of mud or sediment in the tubes. The hydraulic circuit of the condenser is capable of being handled much like an electric circuit. The differential pressure across a condenser varies greatly with the quantity of water flowing through it, but it also varies considerably at constant water flow with different amounts of trash obstructing it, particularly if the obstructing material is to a considerable extent leaves which become plastered over the tube plate.

Again, where open intake wells are used, the fluctuation of levels in them may depend upon more than mere tide level variation. Measurable lost head may occur in them due to perforated openings designed to stop obstructing materials which might be harmful to the circulating pumps. Variation of quantity of water circulated due to any cause will then cause variation of this lost head, but if at some constant quantity of circulating water the lost head in the circulating pump suction line increases to values appreciably above normal the bottom of the open intake well may need cleaning out. The absolute pressure which an air pump can maintain against a closed suction value has been discussed before. Nothing is more important in vacuum maintenance. It is the prime indication of the pumping ability of the pump. To show forcibly how even the degree of air leakage itself is not more important and may in some installations be distinctly less important than the air-tightness and general perfection of mechanical workings of parts, Fig. 26 is published, showing absolute pressure in the suction lines of various pumps in actual service with large variations of air leakage coming through the air suction lines from the condensers. The quantities of air leakage were measured by an air bell. The solid portions of the ruled straight lines were drawn through actual guarantees of the performance of a certain type of rotary pump in which water jet action extracts the air; the upper line representing one pump and the lower line two. The numerous plotted points all represent actual service performance of reciprocating dry-vacuum pumps. The lesson from the plot is clear. If a reciprocating pump is

in fine condition it may be capable of removing a great amount of air from a condenser and yet maintain admirably low absolute air pressure while it is doing so. On the other hand, through neglect of skillful maintenance work the absolute pressure may not be notably low even though the air leaking into the condenser and needing to be removed by the pump may be moderate in amount, thanks to a tight condenser.

The use of an air bell gives such powerful means of control of vacuum maintenance by putting air leakage measurement upon a quantitative basis that an illustration of such a bell may be of interest, and is accordingly shown in Fig. 27. An air bell made from this drawing has been in satisfactory service for several years. The conception of using such a bell for the purpose did not originate with the company with which the writer is connected. So far as he knows it was first used by the New York Edison Company.

As a refinement in the use of an air bell, a hole may be drilled in the top of it and a rubber stopper inserted through which is passed an ordinary chemical thermometer. In this way the temperature of the air may be measured as the bell rises. This allows correction of the air volume to standard temperature to be made.

PART III

POWER TRANSMISSION AND DISTRIBUTION

By Charles R. Harte, Construction Engineer,
the Connecticut Company, New Haven

CHAPTER XIV

THE FORCES WHICH ACT UPON A TRANSMISSION LINE

THE present-day tendency to broad publicity shows that at last electric railway operators are realizing the fact that they are merchants, their wares being transportation, and that if they are to be successful they must follow modern methods of salesmanship. Transportation, however, is only the last step; before the goods can be sold they must be produced. The complications of this process and the opportunities which it affords for losses or economies all along the line are hardly appreciated except by those most intimately connected with the details. An investigation of the process from the time when the raw material —the fuel—is delivered to the plant to the time when a ride is delivered to the customer, however, shows that it consists of a number of steps. The investigation will disclose also at least one, and in the majority of cases two, interruptions in the manufacturing procedure while the principal "material" of the ride is being shipped from one shop to the next.

Let us start with the coal pile. The chemical energy locked up there must be transformed in the power station first to heat; then through the agency of steam and the turbines or engines to rotary motion; then in the alternators to electrical energy, and finally in the step-up transformers to an entirely different variety of current for "shipment" over the transmission line. At the substation the incoming energy is again changed to an entirely different form of alternating current; then by the rotaries or motor-generators to direct current, to be shipped over the distribution system to the car, wherein the motors convert it first into rotary motion and then, by the aid of wheels and track, into straight line car motion. The electric railway business involves, therefore, not only retailing of transportation, but producing it in three manufacturing plants and providing

two transportation systems to carry the product of each to the next in order.

In the case of a small property, generation, transmission, conversion and distribution may all come under one department, but in larger systems each will have its own more or less complete organization. In a discussion in any detail each step will require individual treatment in many respects.

It is proposed in the series of articles on transmission and distribution lines, of which this is the first, to set out in some detail the purpose and requirements of the several elements, and to describe some of the materials and practices which have come under the writer's observation. It is hoped that their appearance "once in a while" will result in comment, criticism and additional information; that the sum total of the discussion will form a helpful contribution to the art by indicating what to do or, perhaps, that which the late Dr. Thomas Egleston of the Columbia School of Mines always said was equally important to know—what not to do.

In the transmission of power from the power station to the car it passes in general over the high-tension line, through the substation, over the low-tension feeders and finally through the overhead contact line or third-rail to the trolley wheel or shoe. In the present article we shall concentrate attention largely upon the transmission line, and particularly upon that important element, the pole.

The transmission line is a transportation line pure and simple, with the one function of transmitting high-tension current from generating station to substation. Electrically this requires construction which will keep the current on the wire and lightning off it. Mechanically there must be strength to resist storm and decay or corrosion, and supports must be provided to keep the wires out of mischief to themselves or others. In theory apparently these are very simple matters; in practice they are often surprisingly complicated, particularly in the case of the long-distance high-potential heavy-power lines. Such lines, however, are a whole subject in themselves, and indeed are more apt to be part of a big general-service power system than part of an electric railway.

The moderate-voltage transmission lines which make up the large majority of those actually a part of "trolley" systems

have much in common with distribution lines, and to a considerable extent are combined with them. The greatest difference arises from the fact that while the transmission line serves merely as an industrial carrier between two fixed terminals the distribution line must deliver power to a rapidly moving car at any point along the line. In addition to carrying the current it must provide a satisfactory track for the collecting device. This fact gives the transmission line designer a considerable advantage, his mechanical problems differing only in degree from those which the older telegraph line practice had pretty well solved. Naturally the desire of not a few of those entering

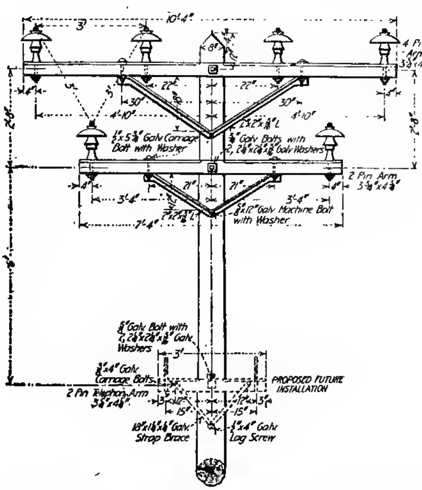


FIG. 28—TYPICAL TRANSMISSION LINE POLE TOP

the new field to impress the stamp of their originality on the art led to some outrageous construction. The one thing that refused to lend itself to "freak" treatment was the form of support which probably for some time to come, as heretofore, will carry a good majority of the lines, namely, the wood pile.

The Pole Must Be Considered as a Beam. The line poles have three mechanical functions. They must support the dead weight of the line, withstand the tendency of the line and the wind to overturn them sideways, and hold the line sufficiently above the ground to provide adequate clearance.

In its direct effect the dead load is of comparatively little importance as regards the pole itself. Crossarms and other at-

tachments, even though relatively numerous, do not weigh much. The pole top shown in the illustration, which is for two No. 00 copper circuits with 150 ft. normal span insulated for 45,000 volts but to operate at 33,000, has a dead load made up as follows:

Six insulators, 11 lb. each	66 lb.
Six pins, 5 lb. each	30 lb.
Crossarms, 58.5 + 41.5 lb.	100 lb.
Braces, 14.5 + 11.5 lb.	26 lb.
Bolts, etc.	10 lb.
Conductors, 6 x 150 ft., 0.403 lb. per ft.	363 lb.
Total	595 lb.

With the conditions specified in the National Electric Safety Code as "heavy loading," a dead load of 1230 lb. is produced. This provides for a coat of sleet ½ in. thick, making the diameter of each wire practically 1½ in. The specified wind pressure of 12 lb. per foot, which is also a considerable part of the heavy loading, is assumed to act horizontally, and so does not affect the vertical load. The sleet increases the loading by 535 lb., to which must be added probably 100 lb. due to the ice on the arms and the pole itself. This 1230 lb. is far below the capacity of any ordinary pole acting simply as a strut, but its effect on the arm is quite a different story.

Considering the pole as a beam, however, the effect of the loading in conjunction with wind, or in the unhappy case of unbalanced stresses due to some form of failure on either side, is a more serious matter. Before considering this, however, it is well to see what are the forces which must be overcome.

Estimating Maximum Stresses on Transmission Lines. The two forces which may tend to overturn a pole are those due to the wind and to the unbalanced pull of the conductors. The assigning of proper values to these forces in designing a line was the subject of bitter discussion until the appearance in 1911 of the "Specifications for Overhead Crossings of Electric Light and Power Lines." This work was prepared by a joint committee of the National Electric Light Association (at the instance of whose committee on overhead line construction, and particularly of Farley Osgood, chairman of the committee, the work was undertaken), the American Institute of Electrical En-

gineers, the American Electric Railway Association, the Association of Railway Telegraph Superintendents and the American Railway Engineering and Maintenance of Way Association (now the American Railway Engineering Association). The interests of the telephone companies, which have no corresponding national organization, were represented by F. L. Rhodes and H. S. Warren of the N. E. L. A. and A. I. E. E. respectively.

This committee selected the following as reasonable maximum pressures upon sleet-covered structures: 8 lb. per square foot of area of conductors with a coat of sleet increasing the diameter by 1 in. (½ in. of sleet) and 13 lb. per square foot "on the projected area of solid or closed structures and one-and-one-half times the projected area of latticed structures." These pressures correspond to an "indicated" wind velocity of about 70 m.p.h., or an actual velocity of about 60 m.p.h., the difference being due to the fact that the usual cup anemometer gives readings higher than the actual velocities.

Velocities higher than those specified do occur, but almost never with sleet. In the case of large towers in exposed positions such higher velocities against the uncoated surfaces may require special consideration, but as a rule, on the rare occasions when such velocities occur the reduction in area by the loss of the sleet more than offsets the higher pressures.

A Few Peculiarities of Sleet. The production of sleet on transmission lines requires a peculiar condition, namely, a temperature below freezing on the ground with one above freezing higher up so that the rain or wet snow does not freeze until it strikes the line. A very little temperature change fortunately stops the process, but altogether too frequently for the engineer's peace of mind the critical conditions endure long enough to do serious damage. The thickest sleet coat is much of the same class as the biggest trout caught; details are best remembered long afterwards. At the time of the occurrence the sentiment of all involved is apt to be that of a lineman whose failure to get some actual measurements in view of the previous specific requests for facts was mildly commented on by the writer. In this case the prompt "come-back" was "It bust the line; what the h— more do you want!"

Sleet ranges from a porous white and comparatively light form through all grades up to a beautifully clear ice. As a

rule the white ice, some of which is almost as heavy as the clear ice, occurs with heavy winds. The clear ice is apt to form in quieter times, and to be followed promptly by clear cold weather with high wind. However, there seems to be no certainty in the matter and either form of sleet may do great damage.

The severe storms of 1909, one of which "assisted" in the inauguration of President Taft, were of the frozen-snow type. The storm of Dec. 13, 1915, was chiefly one of clear ice. The latter was notable in that, although it left the "overhead" practically uninjured it put the New York division of the New Haven Railroad out of business for several days by wrecking its communication lines. In these particular storms the damage was chiefly due to the weight of the accumulations. It occurred very largely on communication lines, the heavy leads of light wire affording a particularly good opportunity for trouble.

How Geography Affects the Sleet Question. The evidence collected since the work of the joint committee was completed has shown the fairness and wisdom of its standard, and the ½-in. ice and 70 mile, zero-degree wind have been adopted by the federal Bureau of Standards in the new National Electrical Safety Code, the last word on the subject. In the code, however, the pressure against supports has been taken at 12 lb. instead of 13 lb. per square foot and lighter loading is prescribed for those sections of the country in which heavy sleet storms do not occur.

The district of heavy loading comprises all territory north of a line starting at the mouth of the Potomac River, passing east of Raleigh, N. C., along the line of the southern boundary of Tennessee to the Mississippi, in a southerly direction to Dallas, Texas, and thence northward in a curve cutting off the northeast corner of New Mexico, through the northwest corner of Colorado to a point on the Canadian border about 100 miles east of the northwest corner of Montana.

The region of medium loading lies between this line and one which starts near Beaufort, N. C., runs south of Aiken, S. C., parallels the heavy-load region to a point near Waco, Texas, and thence sweeps west, passing into New Mexico at the Pecos River, through the south corner of Nevada and the valleys of the San Joaquin, Sacramento and Klamath Rivers to the Pacific. In the territory between this and the heavy loading area the maxi-

mum loading of the conductors is assumed to occur at a temperature of 15 deg. Fahr., and to be two-thirds of the value of the resultant wind and ice loads in the heavy loading district unless, as is the case with large conductors, this reduced value is less than one and one-fourth times the weight of the bare conductor. Under such circumstances one and one-fourth times the weight of the bare conductor is to be used, while for the supports the pressure is taken at 8 lb. per square foot. In the district lying south and west of this medium-loading area sleet is practically unknown, and for this section the maximum load is assumed to occur at 30 deg. Fahr., and to be four-ninths of the value of the resultant of the wind and ice loads in the heavy-loading district, but in no case less than one and one-fourth times the weight of the bare conductor. For the supports the pressure is taken at 5⅓ lb. per square foot.

Some Examples and Applications. Let us now get down to the practical application of all of this. The several forces pushing on the pole tend to break it off at the ground line if it is well set. The fibers of the pole resist this tendency, and the problem is to pick a "winner" for the pole.

The force against the pole is practically as follows:

$$\text{Force}_1 = \frac{\text{butt diameter} + \text{top diameter}}{2} \times \text{length above}$$

ground × wind pressure per square foot. The pole dimensions are all in feet.

The effect of this force over the entire length is as if it was all applied at a point midway between top and ground. The force resulting from the wind against each ice covered conductor is:

$$\text{Force}_2 = \frac{\text{conductor diameter} + 1\text{ in.}}{12} \times \tfrac{1}{2}\text{ length of each ad-}$$

jacent span × wind pressure per square foot. The conductor diameter is in inches and the span length is in feet.

In the case of the pole top previously considered the average pole is 35 ft. long, with 6 ft. in the ground; the top diameter is 8 in., and the ground-line diameter is 13 in. For the heavy loading region we have:

$$\text{Force}_1 = \frac{1.08 + 0.67}{2} \times 29 \times 12 = 304.5\text{ lb.}$$

Bending moment at ground line $= 304.5 \times \frac{29}{2} = 4414$ lb.-ft., due to the pole itself.

For each wire:

$$\text{Force}_2 = \frac{0.42 + 1.0}{12} \times \left(\frac{150}{2} + \frac{150}{2}\right) \times 12 = 213 \text{ lb.}$$

For the upper set:

Bending moment $= 4 \times 213 \times 29 = 24{,}708$ lb.-ft.

For the lower set:

Bending moment $= 2 \times 213 \times (29 - 2.67) = 11{,}217$ lb.-ft.

The total bending moment $= 4414 + 24{,}708 + 11{,}217 = 40{,}339$ lb.-ft.

The moment of resistance of the pole in pound-feet is equal to 0.0002638 times the fiber stress in pounds per square inch times the cube of the circumference at the ground line in inches. If we make this equal to the pound-feet bending moment due to the wind we get the fiber stress as follows:

$$\text{Fiber stress} = \frac{40{,}339}{0.0002638 \times 41 \times 41 \times 41} = 2220 \text{ lb. per square inch.}$$

As the breaking strength of chestnut, cypress, Southern pine and Western red cedar is 5000 lb. per square inch and of Northern white cedar 3600 lb. per square inch, sound poles of the first-named woods 41 in. in circumference at the butt would provide, under the conditions given, a factor of safety of 2¼. For Northern white cedar the safety factor would be 1⅔. A factor of safety as low as that for Northern white cedar would make close attention to pole condition desirable and necessitate prompt renewals later on.

It is always desirable by calculation to test the probable strength of the poles used. For the average line "Class B" poles will almost always serve, but definite figures made at the time the line was built are often of great value in later discussions with regulative bodies.

The following table gives the maximum resisting moments of poles for fiber stresses of 5000 lb. and for 3600 lb. The former

is a conservative *breaking* value for sound chestnut, cypress, Southern pine and Western red cedar, and the latter for Northern white cedar. The actual stresses should in no case exceed one-half of the values of the table.

Circumference of Pole at Ground Level in Inches	Breaking Moment in Pound-feet for Fiber Stress in Pounds per Square Inch of		Circumference of Pole at Ground Level in Inches	Breaking Moment in Pound-feet for Fiber Stress in Pounds per Square Inch of	
	5000 lb.	3600 lb.		5000 lb.	3600 lb.
30	35,620	25,650	46	128,400	92,450
31	39,300	28,300	47	136,940	98,600
32	43,220	31,120	48	145,880	105,030
33	47,400	34,130	49	155,200	111,740
34	51,840	37,320	50	164,880	118,710
35	56,560	40,720	51	174,960	125,970
36	61,540	44,310	52	185,460	133,530
37	66,820	48,110	53	196,360	141,380
38	72,380	52,110	54	207,700	149,540
39	78,240	56,330	55	219,450	158,000
40	84,440	60,800	56	231,640	166,780
41	90,900	65,450	57	244,270	175,870
42	97,720	70,360	58	257,350	185,290
43	104,860	75,500	59	270,890	195,040
44	112,360	80,900	60	284,900	205,130
45	120,200	86,540			

It is the general practice to assume that any ordinary unbalanced pull in the direction of the line will not exceed that resulting from a cross-line wind against iced conductors. Pulls resulting from angles, long spans, and possible conductor failures are almost invariably met by special guys or braces. Occasionally, however, it becomes necessary to meet the stress with an unguyed pole, in which case a more careful analysis must be made. This will be considered later in connection with special structures. For the general line the assumption that the weakest point of the pole is at the ground line is sufficiently accurate.

CHAPTER XV

GETTING THE RIGHT WOOD POLES FOR ELECTRIC RAILWAY SERVICE

Low first cost, above all other considerations, leads to, and will continue for some time to result in the use of wood poles as the chief support of most of the light and medium heavy power lines, irrespective of whether or not this is true in the long run. In addition to being relatively cheap, wood poles are easy to handle; they are reasonably available (there are few sections of the country which cannot furnish some sort of local pole); they are easily climbed, and in soft ground they can be successfully used with special but relatively inexpensive construction where steel or concrete structures would require very costly foundations.

Poles Last About Twelve Years on the Average. As against these advantages, wood poles are comparatively short-lived. This is due to decay (which accounts for about 95 per cent of the replacements), insect attack, fire, lightning stroke, woodpecker injuries, and sleet and wind storms.

In the years 1907 to 1911 inclusive, the Department of Agriculture recorded the purchase of some 17,560,000 poles. If we assume that 10 per cent of these were used on new construction, and this is more likely an over-estimate than the contrary, the average annual replacement was about 3,512,000 poles. This on a basis of 40,000,000 poles in use, a generally accepted figure, would mean an average life of twelve years. Such a life checks closely with some figures gathered by the National Electric Light Association. If we multiply the average life of each kind by the ratio of that kind to the total in 1915 we get the data given in Table I.

The above table, however, does not tell the whole story, for the labor of replacing a pole is considerably greater than that of originally setting it, and the disturbance of the attachments not only costs money, but shortens the life of the attachments them-

selves. Altogether the annual bill for wood-pole replacements is a serious matter. Part of the outlay is unavoidable, but a considerable part is unnecessary and should, therefore, be prevented.

TABLE I—LIFE OF TRANSMISSION LINE POLES

Kind of Pole	(*a*) Average Life, Years, N.E.L.A. Data	(*b*) Dept. of Agriculture, per Cent of Total	Product of (*a*) and (*b*) Years
Cedar	13.5	63.9	8.6
Chestnut	12.0	17.5	2.1
Cypress	9.0	2.3	.2
Pine	6.5	6.0	.4
Oak, etc. .... say	8.5	10.3	.9
	"Weighted" Average Life		12.2

There are many species of tree which are sufficiently upright and straight in their habits to permit their use for poles, but most of these give short service life, lack strength, or are scarce so that there are but few which are extensively employed for this purpose. The Department of Agriculture records purchases of 4,077,964 poles of all kinds, for the year 1915; nearly a third of these, however (1,236,694), were under 20 ft. in length. Telegraph and telephone companies took 44 per cent of the total, electric railway and power companies 35 per cent and steam railroads the remaining 21 per cent. The government records, covering the years 1907–1911 inclusive, and 1915, show the relative demands for several leading species of timber as given in Table II.

TABLE II—RELATIVE USE OF SEVERAL POLE WOODS

Kind of Wood	Consumption in 1915, per Cent		Consumption Average, 1901–1911 and 1915, per Cent
Northern white cedar	42.8		
Western red cedar	13.9		
Red cedar	2.9		
Southern white cedar or juniper	2.2		
All cedars		61.8	63.9
Chestnut		15.9	17.5
Pine		13.4	6.0
White oak	4.4		
Red oak	0.5		
All oaks		4.9	5.2
Cypress		1.6	2.3
Redwood, spruce, tamarack, osage, orange, etc.		2.4	5.1

Cedar, which furnishes about two-thirds of the poles used, is long-lived in service, strong, light, straight and of a nature which permits easy and safe climbing by means of spurs. Further, the wide distribution of the several varieties makes it available almost everywhere without prohibitive transportation charges.

Of the four varieties chiefly used, the northern white cedar or arbor vitae is by far the most important, furnishing in 1915 two-thirds of all cedar poles, or 43 per cent of all poles. This was nearly three times as many as were furnished by the next most important wood, chestnut.

Winter-Cut Poles Are Best. Cedar is a common swamp tree in the Lake and the Northeastern States and in Canada, the bulk of the supply, however, coming from the Lake States. Like practically all timber it should be cut when the sap is not flowing as the sapwood contains the least amount of food for the fungi and other causes of decay. Further, unless the seasoning is done very slowly, the rapid evaporation of the large amount of water present if the sap is flowing is likely to cause serious checking.

It is accordingly quite customary to specify "winter cut" poles, but in very few cases is any effort made to determine whether or not the specifications have been complied with. It so happens, however, that winter is the most convenient time for cutting poles, hence the majority of poles, fortunately, meet the specification. Distinguishing "winter cut" wood from "summer cut" is in most cases, if not always, much like distinguishing "bled" yellow pine from "unbled"; unless the facts are known it is practically impossible to do it.

Western red cedar, known also as red cedar, Western cedar, or Idaho cedar, ranked third in importance in 1915, 13.9 per cent of the poles used being of this species. It is being cut chiefly in the region of the lower Columbia River, of Puget Sound and of northern Idaho. It, however, is much more widely distributed than this. Poles from the Columbia are said to be much freer from butt rot and to weigh more than those from the other localities; otherwise there is said to be little difference.

Western cedar is a very straight-growing tree and furnishes poles of particularly fine appearance. Its chief shortcoming is that it tapers but slightly, hence to secure the necessary butt diameter for heavy service, poles much longer than would other-

wise be needed must be cut. In spite of the freight charges, Western cedar has been able in the past to compete to a small extent with chestnut even in the territory of the latter. With the serious reduction of the supply of chestnut as a result of the spread of the blight, its more extended use in the East is almost certain.

Red cedar, which furnished 2.88 per cent of the 1915 supply, occurs throughout the East. In the Northern States the trees are usually too short and too crooked for use as poles, but in the South they grow tall and straight. The heartwood lasts for a long time in the ground, but the sapwood decays very rapidly, giving the untreated pole a comparatively short life.

Southern white cedar, better known as juniper, furnished 2.19 per cent of the 1915 cut. Like red cedar its use is largely local, due, however, not to other demands for the wood, but to the fact that it is one of the less desirable poles, having a fiber strength in pounds per square inch of 3300, against 3600 for Northern white cedar, 4200 for red cedar and 5100 for Western red cedar. Moreover, its life, untreated, is but eight and one-half years against thirteen and one-half years for the others.

Chestnut Is Hard Hit by the Blight. Chestnut has heretofore furnished a much larger proportion of the poles than any of the woods except cedar, the percentage in 1915 being 15.98. However, the enormous destruction of the trees of this species by the "blight," or bark disease, the effect of which is now being widely felt, is certain to make it much less important for some time to come.

Growing freely in most of the eastern part of the country, its mechanical strength, long service life, straightness, height and wide distribution have made chestnut a general favorite. It is, however, considerably heavier than the cedars, is not so straight and, if we except juniper, is not so long-lived in service, averaging, untreated, twelve years as against thirteen and one-half years.

In 1905 the chestnut trees were first attacked by a fungus which feeds on the inner bark and the outer growing, or cambium, layer of the wood. In 1908 the loss of ornamental chestnut trees was estimated by the forest service of the Department of Agriculture to be "certainly several million dollars." Since that time the plague has spread until to-day there is com-

paratively little chestnut left east of the Appalachians and north of Virginia. So far no practicable method of prevention is known. Fortunately the wood itself is practically unaffected, and on the death of the tree the fungus also dies. It has, therefore, been possible to use much of the larger timber, but the loss of the young wood is now beginning to be seriously felt. Under the most favorable circumstances there will be a considerable period when the available pole material of this wood will be almost nil.

Chestnut grows from individual seed, or from groups of sprouts from live stumps. In the former case it is usually straight throughout, but in the latter the several trunks grow out at an angle of about 60 deg. for a few feet, thus getting clearance, and then rise vertically. In pole stock this bend usually occurs not over 6 ft. from the butt, so that it comes at or below the surface and affects neither the appearance nor strength of the line, although the unset pole may appear hopelessly crooked to one not accustomed to this peculiarity.

Pine Poles Require Treating for Long Life. Pine until recently has made up less than 5 per cent of the total pole supply, due to the fact that although it is one of the strong pole woods, it has the shortest service life of any unless treated. There is also a great demand for it for other purposes. The heartwood is fairly long-lived in the ground, but the sapwood, which is a large portion of most kinds of pine, decays very rapidly.

Of the Southern pines, the long-leaf variety does not take preservative treatment very well. It has been used to some extent for sawed poles, but the well-justified dislike for such poles and the value of the wood for other purposes are steadily reducing the proportion of this species in use for poles. Short-leaf pine has more sapwood, and so takes preservative better, but its value for lumber also cuts down its use for poles, and it is weaker than long-leaf pine. "Loblolly" pine, which is steadily growing in importance, unlike most pole materials, requires treatment all over and not merely at the butt. So treated it has long life and, while the weakest of the three kinds of pine mentioned, its strength is about the same as that of the Northern white cedar.

Western Yellow Pine Has Good Qualities as Pole Wood. Western yellow pine when treated makes a good pole for local use, particularly if hill grown. Such stock is better shaped,

finer grained and stronger than that from the valleys. Untreated it lasts barely three years, but it takes preservative readily and in many parts of the Southwest where this pine is common, a butt-treated pole is cheaper than Idaho cedar untreated, due to the high freight charges on the latter. It has substantially the same service value. Its use is steadily increasing, and in 1909 it was estimated that the supply was more than half as much as the combined supply of all the hard woods in the United States. It grows freely and rapidly, with a strength practically that of Western red cedar. In view of these facts it is quite likely to become one of the more important pole woods of the near future. The best stock is found on the Pacific Coast, but the tree grows commercially in more than a third of the United States.

"Lodgepole" pine, untreated, has the family weakness, but takes preservatives readily. In its own territory, which is the mountain section of the West, it is steadily growing in popularity. Although it is widely distributed its low strength, about 75 per cent that of the Western red cedar, will probably confine its use as at present to a limited territory. Lodgepole is a slow growing tree and one that has been extensively killed by forest fire. Much of the wood so killed, however, is in fine condition for treatment, for it has been thoroughly dried out and as long as the wood remains sound, which is often for many years, it is at least as good as if live cut.

The Department of Agriculture figures show almost exactly three times as many pine poles purchased in 1915 as the annual average for the years 1907 to 1911 inclusive, and although the percentage of each species used is not given, this increase is in all probability due largely if not entirely to the growing employment of treated poles of species which are less valuable for lumber.

White oak, which furnished 4.36 per cent of the 1915 total and had maintained approximately that position in earlier years, until recently was employed almost entirely in short lengths and on light and comparatively unimportant communication circuits. Its short life, great weight and high cost makes it one of the less desirable pole woods. Although the total number of white oak poles reported in 1915 did not materially differ from those of previous years, there was a very peculiar change-about. The

communication companies, which up to that time had used about 90 per cent of the annual cut, leaving about 1 per cent for power, light and railways and about 9 per cent for the steam roads, in that year took but 19½ per cent, while the steam roads took 73 per cent and the electric companies 7½ per cent.

Red oak has all the shortcomings of white oak, and in addition some of its own. Its use is so limited that it hardly deserves mention. It is used almost entirely on light short-pole communication circuits of minor importance. It furnished but 0.53 per cent of the total cut of 1915.

Cypress Seems Better for Shingles than Poles. Cypress, which produced 1.66 per cent of the 1915 poles, has shown since 1907 a steady falling off, not only in percentage but in actual number of poles cut. It is a slow-growing swamp tree of the South, of peculiar characteristics. The sapwood decays rapidly, but the heartwood has an extremely long life. Many instances are recorded where shingles have been in service for more than 100 years. Greenwich, Conn., Brooklyn, N. Y., and Clifton, Staten Island, N. Y., have reported shingles still in service after 200 years. Brooklyn claims 228 years' life for the shingles, and Greenwich, 250 years. In its home territory cypress makes a very satisfactory pole, but elsewhere it has shown much variation. One case was reported in the Northeast where a line of unusually heavy poles had a life of less than 5 years.

Redwood, used locally on the Pacific Coast, furnished nearly 1 per cent of the total cut of poles in 1907. The reports show wide variations in different years, the number in 1915 being too small to record separately. The poles are strong and durable, and as they are almost always if not invariably sawed from large logs, there is no trouble in securing uniformity of size and taper.

There Are "Also-Rans" Among Pole Woods. Besides the above-named woods there is an extensive list of "also-rans," a few of which are very good, but too rare for any but very local use. Others are used because they are the cheapest, or the only material available.

A number of these are as follows, the approximate ratios of the maximum use of some of the most important to the total being given: Balsam, bois d'arc (0.5 per cent), butternut, catalpa, cherry, chinquipin, cottonwood, douglas fir (0.7 per cent), elm, hemlock, locust (0.3 per cent), mulberry, osage orange (0.6

per cent), sassafras, spruce (0.3 per cent), tamarack (0.8 per cent), walnut and willow.

Averaged over a number of years, however, the proportion of the woods used is very small and they usually are reported under the charitable mantle of "all others." Throughout the Middle West and the West, particularly, are many miles of "independent" and country party lines which employ of necessity anything to which their wires can be attached, many of the "poles" being living trees. The fact that of the "all other" poles which made up 2.44 per cent of the 1915 total, practically half were under 20 ft. in length, and 39½ per cent more were between 20 and 29 ft., clearly indicates the character of lines on which they were employed.

Practical application of the above information can only be made in the light of local facts. Other things being equal the local pole is obviously the one to use. As against one or more of the superior virtues of longer life, greater strength or better appearance of the foreign pole must be weighed its cost at the hole, including not only the f.o.b. price, but the freight, handling and hauling charges. Sometimes poles can be hauled direct from car to hole, but often they must be stored for a time, in which case there are not only the double handling charges, but yard service and fire and accident insurance, all or part of which can generally be avoided in the case of local poles.

Weight should also be given to the fact that a wood which has a long service life in the locality where grown may show much shorter life elsewhere. This is apparently due to the same fact which makes possible the various inoculations against disease. A light form of the given or a related disease often leaves in the system of both animals and plants a substance which is poison to other "bugs" of the same kind. The local tree, through a mild attack while alive, has stored up that which for some time keeps the local form of decay from the pole; but this is of little or no avail against the different fungi or bacteria of another region. The case of cypress, referred to previously, is apparently of this kind. It should also not be forgotten that a local material, short lived if untreated, may as the result of treatment show better results than a higher grade of foreign timber. Finally it must be remembered that, in replacing a pole, not only is there the direct cost of the work, but the disturbance of the attachments

always shortens their service life, and in many cases leads to the immediate replacement of material which, if untouched, would be good for some time longer.

The injuries to which wood pole-stock is subject naturally divide into two classes, those occurring before use as poles and those occurring in service.

"Rot" Is the Principal Enemy of Pole Life. "Rot" is the result of the action of plant life, chiefly fungi, but of bacteria to some extent also, the general effect of the two being the same. Through the action of these parasites the cell structure of the wood is broken down, leaving a mass with little or no strength. The appearance of the rot depends on the kind of wood and the "villain" that produced it. Except in name it is identical with the decay which occurs after a pole has been set, but the term "rot" is generally used for internal breakdown which occurred during the life of the tree.

"Butt rot" is the least serious of these evils, because it is so obvious that its extent can readily be determined. It is common in the cedars and occurs more or less frequently in almost all pole woods, but unless it takes up more than 10 per cent of the butt section, or extends above the ground line when the pole is set, it is of little importance. The action does not continue after the pole has seasoned unless the cavity is open to the air as well as to moisture.

"Heart rot" and "ring rot" are much more serious because of their concealment, although signs are almost invariably present which to the experienced pole man at once tell the story. The majority of the rots require air, moisture, and heat for their development. Their occurrence inside the pole is possible only as some opening admits the two first-named, and inspection will usually reveal the holes, or decayed or loose knots, responsible for the trouble. Tapping will reveal the presence of hidden cavities by the characteristic sound.

Bacteria and Fungi Must Be Kept Out of the Poles. "Shakes" and "checks" are cracks resulting from wind action or from too rapid seasoning. "Ring," or "cup shakes," involving separation on the lines of growth, usually result from the swaying of the tree in the wind and doubtless indicate a previous weakness in the growth. "Star shakes," "star checks," "checks" and "cracks" are radial splits of greater or less extent

and may be the result of wind action, of abuse when the pole was cut, or of too rapid seasoning with consequent irregular shrinkage and cracking.

"Cat faces" are spots which have been stripped of bark at some time, and over which the bark has never entirely grown again, leaving a round spot of dead wood. Sometimes there is but a thin shell of this dead wood and beneath it the wood is perfectly sound. However, like any bark injury which reaches the wood, it is an invitation for fungus to enter which is quite likely to be accepted. The scar is looked upon with a suspicion often well justified by the heart or ring rot which has resulted through it.

Knots are obviously unavoidable in natural sticks, and so long as they are sound no criticism can reasonably be made of their presence except possibly on the ground of appearances. If the knots are discolored or at all loose or decayed it is quite another story, and rejection of the pole is almost invariably the part of wisdom. If rot has not already occurred inside it certainly will unless special measures are taken to prevent it from doing so.

Ant, grub, and worm holes in themselves are usually not important, but, unless they are of very small extent and will be below the groundline when the pole is set, their presence indicates existing or probable trouble in the wood itself. Further they are apt to lead woodpeckers into investigations which if they do not directly result in weakening the pole, give the rain and the rots an opportunity to enter.

Cypress is subject to a disease which, so far as the writer is aware, attacks no other pole timber, or at least no other important pole timber. It is true, however, that the "incense cedar" of the Pacific Coast is subject to "pin rot," which is somewhat similar. In the cypress a fungus eats holes through the wood of the living tree, which are from a quarter of an inch to an inch wide and often several inches long. The holes are frequently bored in very great numbers, seriously reducing the strength of the wood, although oddly enough it at least does not seem to reduce its resistance to decay. It is commonly believed that the "pecky cypress," as it is called, lasts very much longer than the unaffected wood.

In many specifications the writers have included unwarranted objections to "dead," "fire killed," or "river" poles. There is

a more or less widespread prejudice against the use of poles which show any signs of having died on the stump, although exhaustive tests of the woods most subject to such untimely end have shown no appreciable effect on the life so long as the wood is sound. The better specifications of to-day provide for the acceptance of such poles which show sound wood under a thin dead surface.

The extent to which defects may or may not occur in poles for various services is set out in much detail in many specifications, more or less intelligibly. The following summary of these covers the important elements.

Wood poles must be delivered in piles or on cars at specified delivery points, and will be inspected at points of shipment or of delivery as may be agreed. In either case the shipper must give the purchaser every facility for inspection.

Poles of whatever kind of wood must be first quality, reasonably straight, well proportioned from butt to tip, without short crook, reverse curve, or two or more curves or crooks; they must be barked but not shaved, with knots and limbs closely trimmed and butts and tips squared, and they must be of full dimensions. No allowances will be made for alleged shrinkage said to be due to seasoning or to any other cause.

The poles must be sound, free from butt rot, butt hollows which would impair the strength as poles, large cracks or season checks, large, loose, hollow, unsound, rotten, or plugged knots; ant-eaten, grub-eaten, or worm-eaten wood unless of small extent and below a line 6 ft. above the butt; woodpeckers' holes, cat-faces unless small and sound and not within 6 ft. of the butt or within 10 ft. of the tip; wind-shakes, ring-shakes, or cup-shakes, sap-rot, internal rot or bad tops.

Some Woods Require Individual Specifications. Northern white cedar and Western red cedar, in addition to meeting the above requirements, must have at least three-fourths of the surface free from dead streaks. Dark red or copper-colored surfaces will not be considered cause for rejection if good sound wood lies immediately beneath. No pole will be accepted if it has a twist in excess of one complete twist in 20 ft. of length. Hollow heart in sound butts will be accepted if the circumference at a point 6 ft. above the butt is greater than specifications for sound poles by the amounts given in Table III.

TABLE III—COMPENSATION FOR "HOLLOW HEART" IN POLES

Pole Length	30 ft.	35 ft.	40 ft.	45 ft.	50 ft.	55 ft.	60 ft.	65 ft.
Average diameter of hollow, inches	Circumferences must be increased by these amounts in inches							
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	1	0	0	0	0	0	0	0
4	2	0	0	0	0	0	0	0
5	3	1	1	1	0	0	0	0
6	4	2	2	2	1	1	1	1
7	Reject	4	4	4	2	2	2	2
8	Reject	6	6	6	3	3	3	3
9	Reject	Reject	Reject	Reject	4	4	4	4
10	Reject	Reject	Reject	Reject	5	5	5	5
11	Reject	Reject	Reject	Reject	7	7	7	7
12	Reject	Reject	Reject	Reject	9	9	9	9
13	Reject	Reject	Reject	Reject	Reject	Reject	Reject	Reject

TABLE V—MINIMUM POLE DIMENSIONS, SPECIAL POLES

Length of Pole	Sawed Redwood Dimensions at		Creosoted Yellow Pine Circumference at	
	Top and Ground Class A, Inches	Top and Ground Class B, Inches	Top and Ground Class A, Inches	Top and Ground Class B, Inches
Feet				
30	7 x 7 11 x 11	6 x 6 10 x 10	22 35	20 32
35	7 x 7 12 x 12	6 x 6 11 x 11	22 38	20 34
40	7 x 7 13 x 13	6 x 6 12 x 12	22 40	20 36
45	7 x 7 14 x 14	6 x 6 13 x 13	22 42½	20 38
50	7 x 7 15½ x 15½	6 x 6 14 x 14	22 44½	20 40
55			22 47	20 42½
60			22 49	20 44½
65			22 51	20 47
70			22 53	20 49
75			22 55	20 51
80			22 57	20 53

"Ground" circumference to be taken 6 ft. from butt.

TABLE IV—MINIMUM POLE DIMENSIONS, NATURAL POLES

Length of Pole	Chestnut Circumference at Top and Ground, Inches		Crook, Inches	Cedar Eastern White Circumference at Top and Ground, Inches		Crook, Inches	Cedar Western Red Circumference at Top and Ground, Inches		Crook, Inches	Juniper Circumference at Top and Ground, inches	
Feet	Class A	Class B		Class A	Class B		Class A	Class B		Class A	Class B
30	24 40	22 36	10	24 43	22 38		28 37	25 34	5	24 40	22 37
35	24 43	22 40	11	24 47	22 43	10½	28 40	25 36	6	24 43	22 40
40	24 45	22 43	11	24 50	22 47	12	28 43	25 38	7	24 47	22 44
45	24 48	22 47	11	24 53	22 50	9	28 45	25 40	8	24 50	22 48
50	24 51	22 50	12	24 56	22 53	10	28 47	25 42	8	24 53	22 52
55	22 54	22 53	13	24 59	22 56	11	28 49	25 44	9	24 56	
60	22 57	22 56	14			12	28 52	25 46	10	24 59	
65	22 60	22 59	15				28 54	25 48	11		
70	22 63	22 62									
75	22 66	22 65									
80	22 70	22 69									
85	22 73	22 72									
90	22 76	22 75									

"Ground" circumference shall be taken 6 ft. from butt. "Crook" is maximum distance from pole to string stretched from point 6 ft. from butt to point at top.

Scattered rot not less than one-fourth of the diameter from the circumference will be figured as equivalent to hollow heart of the same cross-section; cup shakes, star shakes, and heart shakes will be figured as equivalent to hollow heart area as that checked or shaken.

Redwood poles must be sawed from first or second butt-cut logs of sound No. 1 redwood and shall have not over 4 per cent of area in sapwood, nor shall the sapwood be over 1 in. at any point. No transverse cracks will be allowed, and butt hollows, if present, must have sound walls and must not have an area over 10 per cent of the pole section at that point.

Dimensions of Class A and of Class B wood poles must be as given in Tables IV and V.

CHAPTER XVI

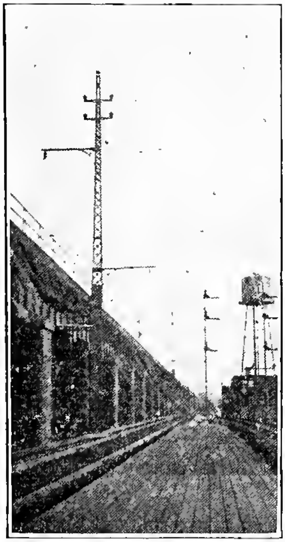
VIRTUES AND LIMITATIONS OF STEEL SUPPORTS IN OVERHEAD CONSTRUCTION

In favor of the use of wood poles in overhead construction are low first cost, ease of framing for any construction, comparatively light weight facilitating both field transportation and erection, and ease of climbing. On the other hand they have to answer for rather short life, involving not only replacement of the pole itself at frequent intervals, but also inevitable injury at such time to the attachments; for liability of burning in case of current leakage or of grass or other fires near by; and in many instances for the appearance if not the fact of obstruction to traffic. With a public not entirely in sympathy with the owners, such appearance is quite likely to lead to agitation for underground construction.

The permanent poles divide naturally into several groups, namely, latticed steel poles, steel towers, tubular poles and concrete poles. The last-named will not be taken up in the present article.

Latticed steel poles are the least common and generally speaking—although there is at least one exception, the Bates pole—the most costly. In fact, until the appearance of the exception referred to, latticed poles were used chiefly in special cases where towers required too much room and tubular poles failed to give the necessary strength. For trolley service they have had some use in a few cities, and they are rather attractive in appearance, but the large amount of labor involved in their construction makes the cost excessive. For heavier service the section is usually square, with angles for corners and latticing outside. If the legs are slightly curved outward at the base, as in the case of the New York Central Railroad poles, the effect is much more pleasing than that produced with a straight taper.

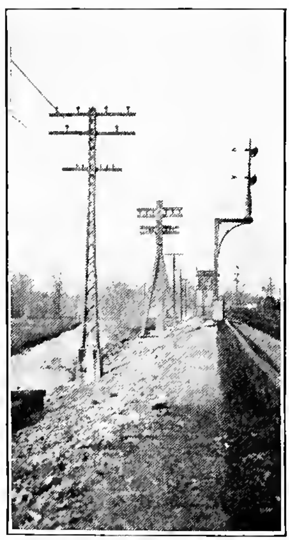
Fabricated lattice poles, being almost invariably used to meet special conditions which fix the dimensions, possibly require spe-



Pole in Restricted Space, Pennsylvania Railroad, Philadelphia Electrification

Pole Used to Avoid Right-of-Way Difficulties, Connecticut River Power Company

Trolley Pole Used at Albany, N. Y.



Pole with Legs Slightly Curved, Used by New York Central Railroad

One-piece Expanded Pole Supported Transmission Line

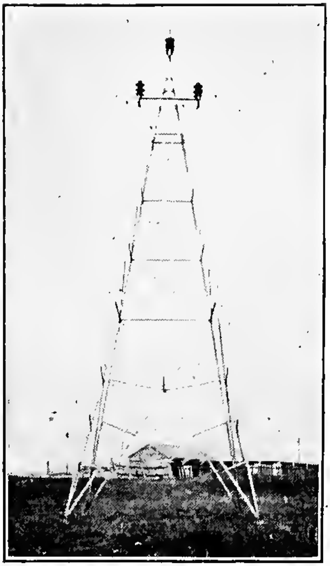
SEVERAL TYPES OF LATTICED STEEL POLES

cial designing. This is best done jointly by the line engineer and the designing engineer of the shop which is to build them, in order that on the one hand the service requirements shall be met and on the other that so far as possible the details follow the regular practice of the shop. Sometimes special construction requires special details, but in the majority of cases this is unnecessary or can be avoided by unimportant changes in the main design. In a small shop doing a large variety of work with a limited equipment special designs and details do not make so much difference, but in a large establishment equipped for quantity production variations from the routine practice not infrequently double both cost and time of production.

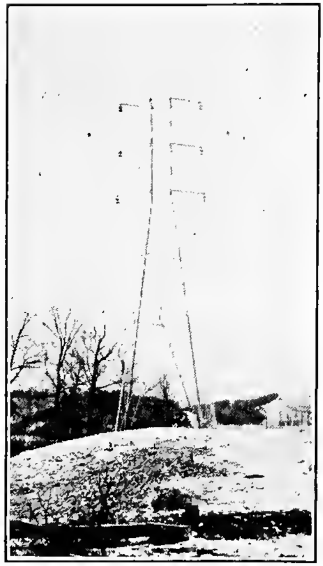
The Expanded Type of Pole Is Promising. The latticed pole which is an exception to the high cost of the majority of types, and which seems to have a considerable field before it, is, at least up to a length of 35 ft., made from a single piece of metal, an H-beam of special section. The web of this is first slit properly by a special rotary punch, and then, after heating, the flanges are pulled apart, the web sections forming the equivalent of lattice bars, with the marked advantage that they do not require riveting. For lengths above 35 ft. two sections are spliced together. While at least at present the available stock and apparatus limits the size and capacity it would seem that heavy service square poles might well be fabricated with considerable economy by using two poles of suitable size of this type with lattice bar or plate connections. They have been employed and, it is claimed, very successfully as legs for short towers.

Grading insensibly into poles are the steel towers, which are used very extensively on transmission lines of voltages above 22,000; and to a constantly increasing extent on the lower voltage lines. Their ability to carry long spans and thus reduce the number of insulators and their insurance against interruptions is supplemented by comparatively low cost.

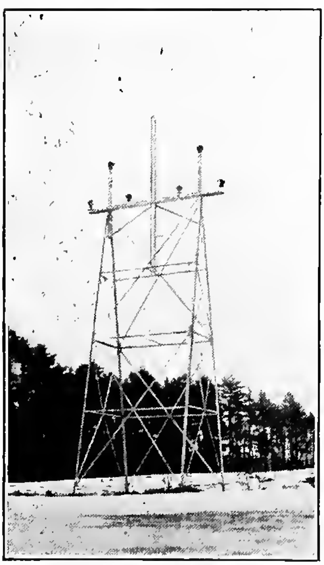
We Owe Something to the Windmill Tower. While in the past there have been designs without end, there is to-day a tendency toward standardization. The steel towers first used were straightaway windmill towers, including the operating platform at the top. The platform long ago disappeared, but the general design, with light angle legs and long and lighter braces, still persists and the towers give good service too. Breakdowns, due



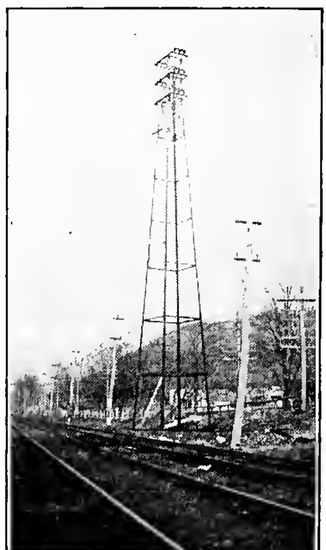
Square Tower on the Line of the Niagara, Lockport & Ontario Power Company



Double-Circuit Tower on the Transmission Line of the Schenectady Power Company



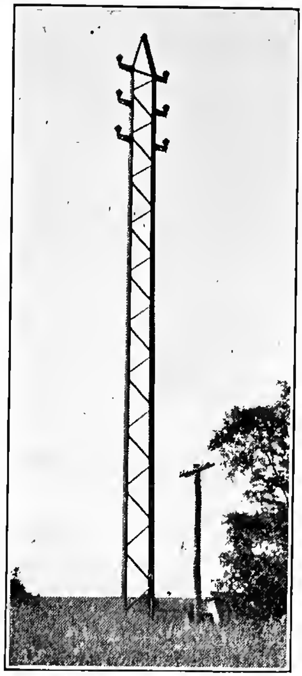
Tower Used for Transmission Line of Connecticut River Power Company



Heavy Type of Tower on the Lines of the Hoosatonic Power Company

TYPICAL STEEL TOWERS USED ON TRANSMISSION LINES

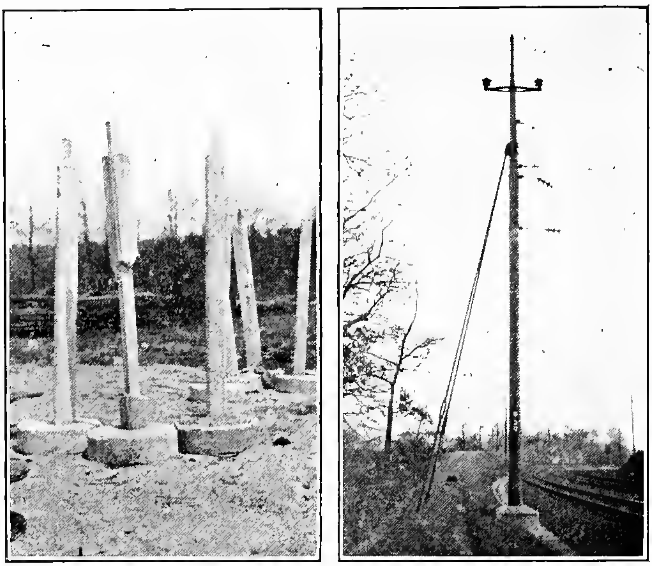
to failure of the designers to recognize the limitations of the type, led to the development of a more rugged design. In this heavy angle legs were designed to carry all the stress, whereas in towers of the very light type it was expected that every member would take a share of the load. Finally, as a compromise between the two extremes there has been developed the scheme which is generally credited to the Italian engineer Semenza, the use of flexible supports.



FLEXIBLE TOWER, BERKSHIRE STREET RAILWAY

The supports of a line must carry the vertical dead load due to the weights of the half spans either side. In addition, when the wind blows there is a force at right angles to the line and each span pulls in the direction of the line. As these forces in general oppose each other the support needs to meet only the *difference* in pulls. If they are balanced, either by making spans and deflections equal or increasing the sag properly on the longer span, the support need only have enough strength to carry the dead load as a column, and sufficient stiffness across

the line to meet the maximum wind effort. Further, other things remaining unchanged, increasing or decreasing the sag decreases or increases the pull in exactly the same relation. For sags which are quite small in proportion to length of span, a very slight decrease or increase in the length of the conductors or, what is practically the same, an equal increase or decrease in the distance between supports without change in the length of conductor between them makes a very considerable decrease or increase in the sag. As a result there is a corresponding in-



At Left, Stub Tower Footings Protected by Concrete Castings (Note how protection has been broken; this is the chief difficulty with this type of footing). At Right, Heavy Tubular Pole with Rod Guys, Pennsylvania Railroad, Philadelphia Electrification

crease or decrease in the pull. A difference in pull, if not excessive, is automatically balanced by a small deflection of the support. In case one conductor breaks, the frame twists as well as bends, but if structural connections and wire ties are good it will usually hold up, and in many cases can be repaired.

The anchor towers for flexible construction are usually standard type square towers with such modification at the top as may be necessary to carry the anchor insulators. The intermediate supports are generally the so-called A-frames with channel-iron

sides and braces, the latter being horizontal, and round rod diagonals. These are almost always fabricated in the shop and sent out complete except for the insulator brackets, which are as a rule of malleable iron, and are bolted on in the field. A form which also is frequently used is practically a latticed pole, having no horizontal bracing, the diagonals being angles or channels with the ends bent so they can be riveted to the legs on the center line of the webs.

Judiciously used, the flexible support scheme is exceedingly good; but unfortunately its reputation has suffered because of over-enthusiasm of some of its advocates. With anchors at proper intervals, the lengths of which will depend upon the conditions and will vary from one to six per mile, and with a ground wire securely attached to each frame so it acts as a continuous tie, a flexible support line should be practically as dependable as one with rigid towers. If it is not so anchored, however, there is a possibility of stresses accumulating at one span under heavy loads, breaking the conductors and wrecking the line back to the nearest anchors. The use of guys in the direction of the line often obviates the necessity for some of the anchor towers.

Peculiar conditions demand special designs of towers, but for the average case there are several lines of stock design from which there can be chosen a form practically if not quite as good as a special type, and at much less cost. With the larger bridge companies regularly making towers, and at least one company specializing in them, there is less occasion for insisting on high factors of safety than was the case a few years ago. Furthermore the designs have been so rationalized that it is possible to get a fair idea of the probable behavior under load. Practically any reputable concern which has had considerable experience in building towers can furnish either directly or with very little modification a stock design which fully meets requirements. For this purpose a broad specification of the service required is necessary, including in this data as to the loads to be sustained and whether pin or suspension-type insulators are to be used. In the latter case particular attention must be given to insure that there are ample clearances for a swinging conductor.

As to what stress a tower should stand in the direction of the

TABLE I—DEFLECTIONS OF EXPANDED POLES FOR GIVEN LOADS (MANUFACTURERS' DATA)

Section	Length in Feet	Set in Ground, Ft.	Base of Pole in Inches	Weight in Pounds	DEFLECTION IN INCHES UNDER VARIOUS DEFLECTING FORCES																											
					200 Lb.	400 Lb.	600 Lb.	800 Lb.	1000 Lb.	1200 Lb.	1400 Lb.	1600 Lb.	1800 Lb.	2000 Lb.	2200 Lb.	2400 Lb.	2600 Lb.	2800 Lb.	3000 Lb.	3200 Lb.	3400 Lb.	3600 Lb.	3800 Lb.	4000 Lb.	4200 Lb.	4400 Lb.	4600 Lb.	4800 Lb.	5000 Lb.	5200 Lb.	5400 Lb.	5600 Lb.
4 In.	20	4	7½	246	0.23	0.65	1.04	1.61	2.34	2 92	3.27	4 62	5 17	5 74	6 13																	
	25	5	8¼	308	0 63	1.63	2.18	3.50	4.50	5.63	7.00	9.06																				
	30	5½	9¼	370	0.75	2.25	3.81	5.63	8.18	10.25																						
	35	6	10	430	0 88	2 63	5 00	7.88																								
5 In.	20	4	9¼	322	0.23	0 45	0.71	1.08	1.42	1.75	2.14	2 70	3.58	4 39	5 64	6 15																
	25	5	10½	403	0 44	1 03	1.53	2.25	2.94	3.65	4.31	5 25	6.65																			
	30	5½	11½	483	0 81	1.31	2 05	3 12	4.62	5.50	7 18																					
	35	6	12½	564	1.06	2.06	3.31	4.56	6.00	7 56																						
6 In.	20	4	11¼	404	0 18	0 31	0.45	0.58	0 74	0.83	1.11	1 35	1.66	2 11	3 42	4.46	5 99	6 69														
	25	5	12½	506	0.50	0.87	1.25	1.62	1.87	1.87	2.87	3.62	4.50	5.75	7.25	8.75																
	30	5½	13¼	607	0.50	0.87	1.25	1.62	2.31	2.93	3.37	4.12	5.12	6.56																		
	35	6	15	708	0 63	1 25	1.88	2.50	3.38	3.88	4.88	5.63	6.63																			
7 In.	20	4	13	498	0.11	0.18	0.26	0.34	0.43	0.49	0.65	0.79	0.97	1.24	2.00	2 61	3 51	3 76	4 02	4.26	4.47	4.69	4.92	5.17	5 43	5 70	5.93	6 17	6 42			
	25	5	14½	622	0 29	0.51	0.73	0.95	1.10	1.10	1.68	2.12	2.63	3.37	3.70	4.07	4 40	4 71	5.04	5.34	5.61	5.89	6.18	6 49	6.81	7.15						
	30	5½	16	747	0.30	0.54	0.78	0.98	1.35	1.71	1.97	2.41	3.00	3.84	4.22	4.60	4.97	5.32	5.69	6.03	6.33	6.65	6.98	7.33								
	35	6	17½	871	0.37	0 73	1.10	1.47	1.98	2.27	2.86	3.30	3.89	4.98	5.47	5 97	6 45	6.90	7.38	7 82	8.12											
8 In.	20	4	15	585	0.07	0.12	0.17	0.22	0.28	0.31	0.42	0.50	0.62	0.79	0.87	0.95	1 03	1.10	1.18	1.25	1.35	1 42	1.49	1 56	1.64	1.72	1.79	1.86	1.93	2.00	2.08	2.16
	25	5	16½	731	0.19	0.33	0.47	0.61	0.70	0.70	1.07	1.35	1.68	2.15	2.70	2.94	3.18	3.40	3.64	3 86	4 05	4.25	4.46	4.68	4.91	5.15	5.35	5.56	5.78	6.01	6.25	
	30	5½	18¼	877	0.20	0.35	0.48	0.62	0.86	1 10	1.26	1.50	1.54	2.45	2.85	3 10	3.35	3.50	3 83	4.06	4.26	4 47	4 64	4.92	5.17	5.43	5.65	5.88	6.12			
	35	6	20	1023	0 24	0 47	0.70	0.94	1.26	1.28	1.83	2.11	2.48	3.18	3 50	3.81	4.12	4 41	4.72	5.00	5.25	5.51	5 79	6 07	6.38	6.69						

Above table of deflections from actual test by dynamometer readings taken one-tenth length of pole below top.

line there is considerable difference of opinion. The National Electrical Safety Code requires that for grades of construction A, B and C, in regions of heavy loading, the wind pressure shall be taken at right angles to the direction of the line and shall be assumed, for cylindrical surfaces, at 12 lb. per square foot of protected area for grade A, 7 lb. for grade B, and 4 lb. for grade C. The conductors are figured as being covered with a layer of ice, increasing the conductor diameter by 1 in., while the supports are figured as bare. For flat surfaces these pressures are to be increased by 60 per cent, making them 19.2, 11.2 and 6.4 lb., respectively. Latticed faces are taken as having an area 50 per cent greater than actual, to allow for the effect of the wind blowing through the spaces and so against the inside of the opposite face, unless this gives a total pressure greater than would result if the structure were solid. In this case the latter value should be used.

Steel structures are required to have a minimum factor of safety of two against these stresses. The use of guys to secure this is considered undesirable although they can be used if necessary. In the latter case if the support can deflect much the guys must be capable of taking all the stress, the support being considered as acting only as a strut.

When steel supports or towers are used which will not stand as great stresses longitudinally as those prescribed for the transverse strength, anchor towers capable of withstanding the total pulls of all the conductors up to a maximum of 10,000 lb. plus one-half the excess above 10,000 lb. shall be placed at intervals not greater than ten spans apart.

The code requirements have in mind protection to the individual and do not apply to lines in the country, but maintenance of service practically demands similar construction standards. And there is a point in this connection which is often missed. The transmission or distribution lines, even when most substantally built, represent but a very small percentage of the total cost of the system. The interest on the idle investment plus the loss of revenue during a short shutdown due to a line failure will very nearly pay the difference between "cheap and nasty" construction and a first-class line.

Steel Templates Are Best in Setting Tower Footings. Tower foundations are of several types. For structures subject to

TABLE II. TUBULAR STEEL POLES—DEFLECTIONS AND LOADS

Length of Pole	Description of Poles								Pole set 6 ft. 0 in. in ground—load applied and deflection measured 18 in. from free end, probable deflections when held and loaded as stated													Greatest Safe Load	Length of Pole
	Size and Kind of Pipe				Weight of Pole	Section Lengths			Load in Pounds Applied 18 in. from Free End of Pole														
	Butt		Middle	Top																			
	Standard	Extra Heavy	Standard	Standard		Butt	Middle	Top	100	500	600	800	1,000	1,200	1,400	1,600	1,800	2,100	2,400	2,700	3,000		
(Ft.)					(Lb.)	(Ft.)	(Ft.)	(Ft.)	(In.)	(In.)	(In.)	(In.)	(In.)	(In.)	(In.)	(In.)	(In.)	(In.)	(In.)	(In.)	(In.)	(Lb.)	(Ft.)
28	5	....	4	3	385	18	7	6	1.23	....	....	....	....	....	....	....	....	....	....	....	....	443	28
28	....	5	4	3	495	18	7	6	.90	4.52	5.42	....	....	....	....	....	....	....	....	....	....	603	28
28	6	....	5	4	509	18	7	6	.65	3.24	3.89	....	....	....	....	....	....	....	....	....	....	692	28
28	....	6	5	4	681	18	7	6	.46	2.28	2.73	3.64	....	....	....	....	....	....	....	....	....	993	28
28	7	....	6	5	645	18	7	6	.39	1.93	2.32	3.09	....	....	....	....	....	....	....	....	....	992	28
28	....	7	6	5	906	18	7	6	.26	1.27	1.53	2.04	2.55	3.06	3.57	....	....	....	....	....	....	1,525	28
28	8	....	7	6	791	18	7	6	.25	1.23	1.48	1.98	2.47	2.97	....	....	....	....	....	....	....	1,366	28
28	....	8	7	6	1,058	18	7	6	.17	.84	1.01	1.34	1.68	2.02	2.35	2.69	3.03	....	....	....	....	1,990	28
28	9	....	8	7	951	18	7	6	.17	.83	.99	1.32	1.65	1.98	2.31	2.64	2.97	....	....	....	....	1,817	28
28	....	9	8	7	1,218	18	7	6	.12	.59	.71	.94	1.18	1.42	1.65	1.89	2.12	2.48	2.83	....	....	2,527	28
28	10	....	9	8	1,137	18	7	6	.11	.57	.68	.90	1.13	1.36	1.58	1.81	2.04	2.37	2.71	....	....	2,432	28
28	....	10	9	8	1,393	18	7	6	.08	.41	.50	.66	.83	1.00	1.16	1.33	1.49	1.74	1.99	2.24	2.49	3,205	28
29	5	....	4	3	393	18	7	7	1.45	....	....	....	....	....	....	....	....	....	....	....	....	422	29
29	....	5	4	3	503	18	7	7	1.07	5.35	....	....	....	....	....	....	....	....	....	....	....	575	29
29	6	....	5	4	520	18	7	7	.76	3.83	4.58	....	....	....	....	....	....	....	....	....	....	658	29
29	....	6	5	4	692	18	7	7	.54	2.67	3.21	4.28	....	....	....	....	....	....	....	....	....	947	29
29	7	....	6	5	659	18	7	7	.45	2.26	2.72	3.63	....	....	....	....	....	....	....	....	....	946	29
29	....	7	6	5	920	18	7	7	.30	1.49	1.79	2.38	2.98	3.58	4.17	....	....	....	....	....	....	1,450	29
29	8	....	7	6	811	18	7	7	.29	1.44	1.73	2.31	2.88	3.46	....	....	....	....	....	....	....	1,304	29
29	....	8	7	6	1,078	18	7	7	.20	.98	1.18	1.57	1.96	2.35	2.74	3.14	3.53	....	....	....	....	1,900	29
29	9	....	8	7	974	18	7	7	.19	.96	1.15	1.54	1.92	2.30	2.69	3.07	....	....	....	....	....	1,733	29
29	....	9	8	7	1,241	18	7	7	.14	.69	.82	1.09	1.37	1.64	1.92	2.19	2.46	2.88	3.29	....	....	2,410	29
29	10	....	9	8	1,166	18	7	7	.13	.65	.77	1.03	1.29	1.55	1.81	2.06	2.32	2.71	....	....	....	2,320	29
29	....	10	9	8	1,422	18	7	7	.10	.48	.58	.78	.97	1.16	1.36	1.55	1.74	2.04	2.33	2.62	2.91	3,060	29
30	5	....	4	3	406	18	9	6	1.67	....	....	....	....	....	....	....	....	....	....	....	....	403	30
30	....	5	4	3	516	18	9	6	1.23	6.16	....	....	....	....	....	....	....	....	....	....	....	550	30
30	6	....	5	4	539	18	9	6	.88	4.39	5.27	....	....	....	....	....	....	....	....	....	....	629	30
30	....	6	5	4	711	18	9	6	.62	3.08	3.70	4.93	....	....	....	....	....	....	....	....	....	906	30
30	7	....	6	5	682	18	9	6	.52	2.60	3.12	4.17	....	....	....	....	....	....	....	....	....	903	30
30	....	7	6	5	943	18	9	6	.34	1.71	2.06	2.74	3.43	4.12	....	....	....	....	....	....	....	1,387	30
30	8	....	7	6	840	18	9	6	.33	1.65	1.99	2.65	3.31	3.97	....	....	....	....	....	....	....	1,245	30
30	....	8	7	6	1,107	18	9	6	.23	1.12	1.35	1.80	2.25	2.70	3.15	3.60	4.05	....	....	....	....	1,815	30
30	9	....	8	7	1,008	18	9	6	.22	1.10	1.33	1.77	2.21	2.65	3.09	3.54	....	....	....	....	....	1,655	30
30	....	9	8	7	1,275	18	9	6	.16	.79	.95	1.26	1.58	1.90	2.21	2.53	2.85	3.32	....	....	....	2,305	30
30	10	....	9	8	1,205	18	9	6	.15	.74	.89	1.18	1.48	1.78	2.07	2.37	2.66	3.11	....	....	....	2,220	30
30	....	10	9	8	1,461	18	9	6	.11	.56	.67	.90	1.12	1.34	1.57	1.79	2.02	2.35	2.69	3.02	....	2,920	30

31	5		4	3	413	18	9	7	1.95													387	31
31		5	4	3	523	18	9	7	1.44	7.18												527	31
31	6		5	4	549	18	9	7	1.02	5.09	6.12											603	31
31		6	5	4	721	18	9	7	.72	3.58	4.29	5.72										867	31
31	7		6	5	696	18	9	7	.60	3.00	3.60	4.80										865	31
31		7	6	5	958	18	9	7	.40	1.98	2.38	3.18	3.97	4.77								1,325	31
31	8		7	6	860	18	9	7	.38	1.90	2.29	3.05	3.81									1,192	31
31		8	7	6	1,127	18	9	7	.26	1.30	1.55	2.07	2.59	3.11	3.63	4.15						1,740	31
31	9		8	7	1,031	18	9	7	.25	1.27	1.52	2.03	2.54	3.05	3.56							1,585	31
31		9	8	7	1,299	18	9	7	.18	.91	1.09	1.46	1.82	2.18	2.55	2.91	3.28	3.82				2,205	31
31	10		9	8	1,234	18	9	7	.17	.85	1.02	1.36	1.70	2.04	2.38	2.72	3.06	3.57				2,125	31
31		10	9	8	1,491	18	9	7	.13	.64	.77	1.02	1.28	1.54	1.79	2.05	2.31	2.69	3.07	3.45		2,795	31
32	5		4	3	427	19	9	7	2.17													371	32
32		5	4	3	545	19	9	7	1.61	8.02												505	32
32	6		5	4	568	19	9	7	1.14	5.70												578	32
32		6	5	4	749	19	9	7	.80	4.01	4.82	6.42										832	32
32	7		6	5	720	19	9	7	.68	3.37	4.05	5.40										830	32
32		7	6	5	995	19	9	7	.45	2.22	2.67	3.56	4.45	5.33								1,275	32
32	8		7	6	888	19	9	7	.43	2.14	2.57	3.43	4.28									1,143	32
32		8	7	6	1,169	19	9	7	.29	1.46	1.75	2.33	2.92	3.50	4.08	4.67						1,665	32
32	9		8	7	1,066	19	9	7	.29	1.43	1.72	2.29	2.86	3.43	4.00							1,520	32
32		9	8	7	1,348	19	9	7	.20	1.02	1.22	1.63	2.04	2.45	2.85	3.27	3.67	4.28				2,115	32
32	10		9	8	1,274	19	9	7	.19	.96	1.15	1.53	1.92	2.30	2.69	3.07	3.46					2,035	32
32		10	9	8	1,545	19	9	7	.14	.72	.86	1.15	1.44	1.73	2.02	2.31	2.59	3.03	3.45			2,680	32
33	5		4	3	439	19	10	7	2.48													357	33
33		5	4	3	555	19	10	7	1.83													487	33
33	6		5	4	582	19	10	7	1.30	6.49												555	33
33		6	5	4	764	19	10	7	.91	4.56	5.47											798	33
33	7		6	5	739	19	10	7	.77	3.83	4.60											797	33
33		7	6	5	1,015	19	10	7	.51	2.53	3.04	4.05	5.07	6.08								1,255	33
33	8		7	6	910	19	10	7	.49	2.43	2.92	3.89	4.87									1,098	33
33		8	7	6	1,192	19	10	7	.33	1.65	1.99	2.65	3.31	3.97	4.63	5.30						1,605	33
33	9		8	7	1,094	19	10	7	.33	1.62	1.95	2.60	3.25	3.90	4.55							1,460	33
33		9	8	7	1,376	19	10	7	.23	1.16	1.39	1.86	2.32	2.78	3.25	3.71	4.18					2,035	33
33	10		9	8	1,308	19	10	7	.22	1.09	1.31	1.74	2.18	2.62	3.05	3.49	3.93					1,955	33
33		10	9	8	1,579	19	10	7	.16	.82	.98	1.31	1.64	1.97	2.30	2.63	2.95	3.28	3.94			2,580	33
34	5		4	3	454	20	10	7	2.75													343	34
34		5	4	3	575	20	10	7	2.03													467	34
34	6		5	4	601	20	10	7	1.44	7.21												531	34
34		6	5	4	792	20	10	7	1.01	5.08	6.09											768	34
34	7		6	5	763	20	10	7	.86	4.28	5.13											767	34
34		7	6	5	1,053	20	10	7	.56	2.81	3.37	4.49	5.62									1,177	34
34	8		7	6	939	20	10	7	.54	2.71	3.25	4.33	5.42	6.51								1,057	34
34		8	7	6	1,235	20	10	7	.37	1.85	2.22	2.96	3.70	4.44	5.18							1,543	34
34	9		8	7	1,128	20	10	7	.36	1.81	2.17	2.89	3.62	4.34	5.07							1,405	34
34		9	8	7	1,425	20	10	7	.26	1.29	1.55	2.07	2.59	3.11	3.63	4.15	4.67					1,955	34
34	10		9	8	1,348	20	10	7	.24	1.21	1.45	1.93	2.42	2.90	3.39	3.87	4.36					1,885	34
34		10	9	8	1,634	20	10	7	.18	92	1.10	1.46	1.83	2.20	2.56	2.93	3.29	3.84	4.39			2,480	34
35	5		4	3	469	21	10	7	3.03													331	35
35		5	4	3	595	21	10	7	2.23													450	35
35	6		5	4	620	21	10	7	1.59	7.97												515	35
35		6	5	4	820	21	10	7	1.12	5.60	6.72											741	35
35	7		6	5	787	21	10	7	.95	4.73	5.68											738	35
35		7	6	5	1,091	21	10	7	.62	3.12	3.75	4.99	6.24									1,135	35
35	8		7	6	968	21	10	7	.60	3.01	3.61	4.82	6.02									1,018	35
35		8	7	6	1,278	21	10	7	.41	2.05	2.46	3.28	4.10	4.92	5.74							1,485	35
35	9		8	7	1,162	21	10	7	.40	2.01	2.41	3.22	4.02	4.82								1,355	35
35		9	8	7	1,474	21	10	7	.29	1.43	1.72	2.29	2.87	3.44	4.02	4.59	5.17					1,885	35
35	10		9	8	1,388	21	10	7	.27	1.35	1.62	2.16	2.70	3.24	3.78	4.32	4.87					1,818	35
35		10	9	8	1,689	21	10	7	.20	1.01	1.21	1.62	2.02	2.42	2.83	3.23	3.64	4.24				2,390	35

heavy stresses large concrete footings with anchor bolts are usually employed. A plan which is being followed more and more is to use "stubs," which are practically short extensions of the tower legs with a piece of channel or angle iron at right angles at the end, forming an inverted T. These are sometimes bedded in concrete in place, and sometimes have concrete cast about them at a central yard. More and more frequently they are set directly in the earth, with some rock filling if the tower is to carry heavy stresses or if the ground is soft. Bolts or stubs are best placed by means of a template made of structural steel, which holds them in exactly correct position until the concrete is set or the earth is rammed. Wood templates are cheaper in first cost but are easily injured, and the cost of correcting one wrong footing even in good country, particularly if, as is usually the case, the trouble is not discovered until the tower is raised into position, will eat up the "economy" and more.

Of the other metal supports the diamond, tripartite, and several other special forms of poles are used to a very limited extent. The diamond pole consists of two parts of high strength steel of V-shape, with specially flanged edges. When properly interlocked these form a diamond section which is set so that the main strains come in the line of the diagonals. While this pole is light and strong the joints are said to render it particularly subject to corrosion. Its chief use is for trolley overhead. The tripartite pole has three legs of Bessemer steel, each of U-section, of such dimensions that each size just fits inside the next larger. The legs are held, with the "round" out, by means of spreaders and collars. Of these there is a large variety, so that a great many combinations of leg sections can be made with any one of many tapers. There have been several installations of this type of pole on transmission lines, notably those of the United States Reclamation Service in connection with the Roosevelt Dam project in Arizona, and the Pueblo line of the Anglo-Mexican Hydroelectric Company of Mexico City, Mexico. The first line has both single and double three-phase circuits of No. 2 copper, in spans of from 300 ft. to 400 ft., on poles 40, 45 and 50 ft. in length. The Mexican line has one three-phase circuit of No. 1 copper and a pair of No. 8 telephone wires in spans of from 285 ft. to 350 ft., on poles 43 ft. 7 in. long, with one leg extended 6 ft. above the top of the pole proper to take a ground wire.

There Are Still Too Many "Standard" Tubular Poles. Tubular poles, originally made up from iron pipe, now consist of special steel tubing and are listed in innumerable combinations, while even more can be had as "specials." In 1913 the American Electric Railway Engineering Association "standardized," cutting down the number between the lengths of 28 ft. and 35 ft. to only ninety-six, there being twelve of each length. As a matter of fact it would seem entirely practicable to reduce the list to not more than thirty "regulars," for many of the sizes listed are very heavy for their strength, and it hardly seems necessary to have lengths varying by single feet.

While tubular poles are practically standard for city trolley lines they have had very little use in transmission service except when the latter lines were on trolley poles. They are, however, coming into use in heavy electrification overhead, notably on the Norfolk & Western, the Pennsylvania at Philadelphia, and the New York Connecting Railroad. In these installations poles of extra large size and strength are employed, and with the solid steel-rod guys are really more of the nature of "baby" towers than poles.

The tubular pole tends to corrode both on the inside and at the ground line, "man's best friend" playing no mean part in the latter, although to-day it is almost universal practice to buy tubular poles with a protecting "dog sleeve" extending a foot or so above the ground. Interior corrosion is less serious; it can be prevented by filling the pole with concrete, but the large majority of users believe that the cost of the protection is greater than the results warrant, and the practice is not common.

Table II, from the 1915 report of the American Electric Railway Engineering Association, gives full and most valuable details of tubular poles of standard sizes.

CHAPTER XVII

CONCRETE POLES ARE IN PROCESS OF EVOLUTION

The possibilities of using concrete as a pole material were first tried out in 1856 in connection with the Panama Railroad, the insects of the Isthmus having proved to be too much for wood. The poles were short and stout, having a length of but 12 ft., tops from 6 to 8 in. in diameter, and butts from 12 to 15 in. across. The iron crossarms were fastened to the poles by means of clamping bands.

The first poles were of plain concrete. It would seem that with the dimensions used they should have served well in a sleet-free section, but they proved not to be satisfactory. Whether the concrete was poor, or monkeys used the wires too freely—a source of serious trouble in the tropics—or from some other cause, the poles were very shortly replaced by others reinforced with a wood core 3 in. square. These behaved but little better than the solid concrete poles, for the core swelled and split the casing of concrete.

From the relative dimensions of the parts of these poles it is quite certain that both the wood and the concrete were expected to take parts of the load. In the case of the concrete-covered poles used at a much later date in Switzerland the wood was full size and the thin concrete shell served merely for protection. Incidentally there seems to be some difference of opinion as to the success of the scheme.

Steel Reinforcement Made the Concrete Pole Possible. Not until about 1895 was steel used as reinforcement, when concrete poles so reinforced were tried out both here and abroad. Although the experimenters were loud in their praises of the products, it was some time before there were any worth-while results. This was doubtless due to failure to appreciate the faults of the new construction until the poles were made, and a bad attack of "cold feet" on the part of the enthusiasts immediately thereafter.

A few, however, stuck to the problem, and by 1910 the reinforced concrete pole had become a reasonably practicable structure. Credit for this result is due particularly to the Concrete Pole Company of St. Catherines, Ont., which built several hundred for transmission lines in the Welland Canal district; to George A. Cellar, superintendent of telegraph Pennsylvania Lines west of Pittsburgh, one of the earliest in the field; to the United Traction Company, Albany, N. Y.; and to several others. Since 1910 very satisfactory results have been secured, although the development has been chiefly local. A few companies, notably the Cleveland Railway; the Fort Wayne & Wabash Valley Traction Company; the Marseilles Land & Water Company, Marseilles, Ill.; the New York State Railways; the Oklahoma Gas & Electric Company and the Welland Canal district companies have used very considerable numbers, while but few other companies seem to have employed concrete poles at all.

The life of a reinforced concrete pole depends on several factors. The concrete itself is practically everlasting as regards decay or corrosion, but it may fail through a mechanical injury. The reinforcement cannot rust so long as it is sealed in the concrete and it is also thus protected from electrolysis. But injury to the covering concrete may expose the metal and permit its destruction by corrosion, while under favorable conditions for such action electrolysis may be set up. The resulting expansion of the steel as it corrodes will split off the protecting material and allow the weather also to take a hand in the destruction.

It was feared by many that moisture would work into the metal and rust it; that frost would spall off the concrete from the reinforcement, leaving it unprotected, and that lightning would shatter the poles, but none of these fears has been realized. Where the concrete has cracked, either from contraction when setting or from mechanical stress, there have been some instances of corrosion as would naturally be expected under the circumstances. Lightning, however, in the rare instances when it has been known to strike, has only slightly chipped the concrete, leaving the pole practically as good as new. In the event of a grass fire, or of a conductor grounding on the pole, there is far less liability to trouble than with wood.. A hot fire or a heavy ground may cause spalling of the concrete, but if the injury is not too long neglected the pole can be patched and made

as good as new. With a wood pole any loss of material can be made good only by complete replacement, and it is astonishing how small a bunch of dry grass will serve to set a wood pole going.

In case of failure, reinforced concrete poles do not break off. Wood poles have greater flexibility, and this often relieves a severe load by increasing the sag of the pulling span; but when the ultimate strength is reached they snap, dropping everything. A reinforced concrete pole, because of its greater stiffness, comes more quickly to serious "distress," but although it may be wrecked beyond repair it will only bend. Even if it lets part of the overhead touch the ground it almost invariably holds up part and so keeps the attachments in fairly good shape.

Concrete Poles Can Be Made Attractive in Appearance. Properly treated, a concrete pole is of pleasing appearance, but unfortunately, with a very little neglect in the making it looks very unsightly. Some designs are quite elaborate, as for example the combined light and trolley pole of the Municipal Railway of San Francisco. On the other hand, nothing could be finer than the severe simplicity of the square pole of the same company or that of the Pennsylvania Railroad's Jersey meadows telegraph line, unless it is the standard octagonal pole of the New York State Railways, which latter is not only attractive and substantial but actually costs but little more than the corresponding size in wood.

In several instances where wood poles had been ordered off the streets of certain municipalities the authorities have been so pleased with the appearance of concrete poles that they have permitted their use instead, at a cost much less than that of steel poles, and far less than that of underground construction.

Some Reasons for the Comparative Unpopularity of Concrete Poles. As against these advantages of long life, support of attachments in case of failure of the pole, resistance to fire and good appearance there are several disadvantages inherent in the concrete pole. Good results in making concrete poles require good forms and skilled labor, and unless the number made is large the cost per pole is very apt to be high even for the very simple types. The poles are heavy at best, and require special care and extra labor for handling and erecting, which further adds to the cost, while if molded with holes or gains for

attachments, later changes are not readily made and are apt to be costly, and if such provision is not made it is equally difficult to make any attachment at all. These facts, which are particularly evident when a company first begins to make and use concrete poles, are undoubtedly responsible for the dislike by many companies and the consequent failure to use what is quite likely to be one of the important pole materials of the near future.

The theory of the reinforced concrete poles is very simple. Concrete, with permanence, ease of molding and comparative cheapness, lacks only tensile strength to be an excellent pole material. Steel has very high tensile strength and needs only to be properly combined with the concrete to give the desired results.

The practical application, however, is not quite so simple, for if the steel is not properly proportioned to the concrete, and correctly arranged within the concrete body, the strains are not properly distributed between the two and the pole will either be weak or uneconomical. The forms must be sufficiently strong to remain true and yet must allow proper access to the concrete for working so as to secure good surface and freedom from cavities. Furthermore, the reinforcement must be maintained in correct position while the concrete is being placed.

There are many discussions of the theory of pole design. One of the best of these appeared in the 1916 report of the power distribution committee of the American Electric Railway Engineering Association. The design and practice developed for his company by Carl L. Cadle, chief engineer New York State Railways, Rochester lines, and described in the reports of the same committee for 1915 and 1916, seem easily to be the best of the unpatented methods that have as yet been described.

Hollow as Well as Solid Poles Are Available. Of the patented methods there are several which have had practical test. One of the earliest developed is the "Siegwart," in which the concrete with its reinforcement is plastered on a rotating form. This with the aid of a canvas belt wound spirally outside compresses and forms a hollow round pole. This construction is said to be very satisfactory. Another method, that of Otto and Schlosser, involves the use of centrifugal force. In a hollow form are placed the reinforcements, tied into shape and the concrete form is then closed and rotated at high speed, centrifugal

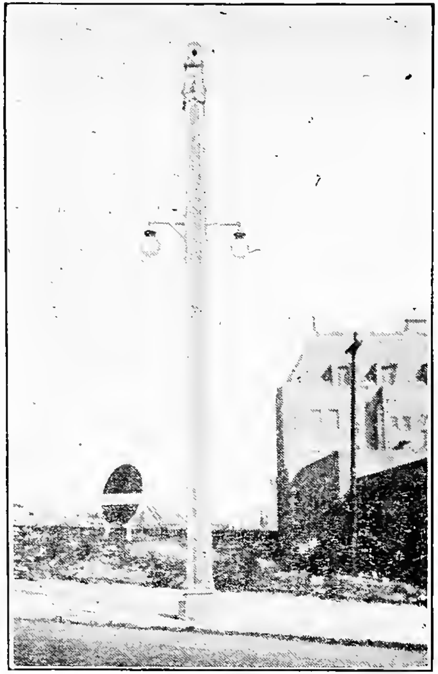
force forcing the concrete firmly against the form. This type of pole is also said to be very satisfactory, but like the Siegwart its use is confined largely if not entirely to Europe.

In this country the Jones process employs a series of compression rolls, an inner core and a canvas belt. The reinforcement is woven to shape in a special machine and put over the inner core, and the combination is laid in the canvas belt between the spread rolls. The proper amount of concrete is then dropped in, the rolls are closed to position and the forming is begun. The canvas draws first in one direction, then back, the length being such as to give about two and a half turns to the pole. Whether this pole has been used to any appreciable extent the writer does not know.

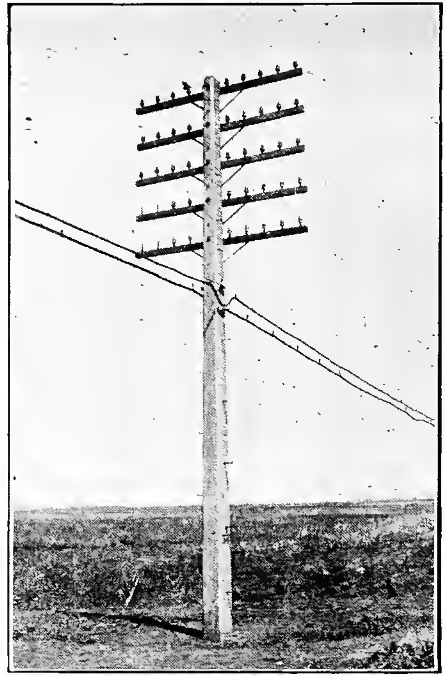
Obviously, after completion the hollow pole is superior to solid poles in the smaller quantity of concrete required and the consequent lightness. But the machine-made types require costly apparatus, and for hand forming the complications of a core have seemed to many experimenters too much of a good thing. F. H. Tidnam of the Oklahoma Gas & Electric Company, has, however, developed a very satisfactory hexagonal hollow-type pole, which is the standard of this company for important lines. This pole is formed in a metal mold, and the collapsible core is removed as soon as the concrete has taken its initial set.

Concrete Poles Cost More Than Wood. The concrete pole to-day is in a very peculiar position. It offers many advantages at any time, but the present shortage of chestnut and the growing importance of other pole woods for purposes which do not allow of substitutes makes its employment particularly attractive. Unfortunately, however, the tendency in regard to its development by the comparatively few who have really gone into the subject in earnest has been to substitute reinforced concrete for wood in substantially the same dimensions rather than to develop a reinforced-concrete support of the most efficient type.

At present, a 30-ft. solid pole, with a breaking strength of about 2500 lb., when it is set 6 ft. in the ground and the load is applied 2 ft. below the top, weighs from 2500 lb. to 3500 lb. The cost ranges from $17.15 in actual cost in quantity, up to $125, the latter figure being a recent bid on a lot of fifty poles exactly like those for which the lower price was paid. Handling, hauling and setting would be about twice as great as



Combined Light and Trolley Pole, Municipal Railway of San Francisco



Pennsylvania Railroad's Telegraph Line Pole on Jersey Meadows

Square Trolley Pole, Municipal Railway of San Francisco

SAMPLES OF SATISFACTORY DESIGNS OF CONCRETE POLES

for wood poles of equivalent strength. The latter would have to have a ground-line circumference of 43 in. and would be cut down from Class A 35-ft., or Class B 40-ft. poles. Recent quotations on such poles, f. o. b. the same points as the concrete poles referred to, were $8 each for chestnut, and $16.35 each for Western red cedar, which would weigh about 1000 lb. and 600 lb. respectively.

Hollow-type concrete poles ought to have a weight and a cost not over two-thirds of the corresponding figures for the solid pole of equal capacity, but while the available information indicates such results the writer has not seen sufficiently definite figures to warrant a specific statement.

Concrete Pole Research Is Greatly Needed Now. The entire subject of concrete pole design, manufacture and use is of the greatest importance. It ought to have a most thorough investigation. For anyone to build one or two concrete poles with the expectation of so solving all the questions out of hand is, however, simply a waste of time and money.

Good reinforced concrete poles were built about 1903, and the number has steadily if not rapidly increased ever since. Moreover many of these are serving their purpose at least fairly well. But the important question is whether or not the work they are doing could not be done just as well by poles of simpler design.

Mathematics and laboratory experiments will point the way, but the determination of how nearly the perfect design can be approached in every-day practice, and just how far short of the performance of the perfect pole the practical article will fall as a result of that difference, can only be found by full size tests. Some of these must be to destruction, and on a sufficiently large number of specimens to eliminate the effect of unusual conditions which might indicate very high or very low values for a single pole.

It is to be hoped that present conditions, which are demanding every possible measure of efficiency, will lead to such thorough investigation of this subject as will develop the practical and economical concrete pole.

CHAPTER XVIII

APPLYING COMMON-SENSE IN LINE CONSTRUCTION

The locations and heights of the supports for a line are usually first laid out in the office, from the location plans and profile. This preliminary determination should then be tested in the field to insure that due regard has been given to the actual conditions. If the plotted information has been complete, the paper location will require little changing, but it frequently happens that the preliminary survey was rushed and that important factors have been overlooked.

An Extreme Case of Failure to Apply "Horse-Sense." On one important transmission line there was a stretch of rolling ground having a distance from top to top of the "rolls" practically that of the spans of the line. The "engineer" who made the profile took his levels in the valleys and the office located the towers also in the valleys, bringing the high spots under the middle of the span. Not until the wires were up was it discovered that in this section the lower conductors were normally only 8 ft. from the ground at mid-span.

On the same line at one point a tower was located on a bit of level ground, but just at the foot of a sharp slope. The outside wire on the side of the slope could actually be touched by a "six-footer" at one point. The undoubtedly high cost of the extensions by which the line was given proper clearance would have been saved, and a number of other undesirable but not actually dangerous conditions prevented, had some one familiar with line construction checked the paper location against the actual conditions. For that matter if the "engineer" in charge of the work had listened to the contractor in a spirit other than one of open hostility the same result would have been secured.

In all construction work there should be close co-operation between the designing and the constructing branches. A contractor's suggestion may be only an effort to get an "extra," but

it is always a good plan to have it looked into on general principles.

Ordinarily the kind of support to be used will be determined first, and the locations and heights afterward. It is possible also that in very rough country, across thickly settled sections and in similar cases, the locations and heights may be fixed and so determine to a considerable extent the character of support required.

If the choice has been wood poles and native wood is used, the poles can generally be purchased delivered at the hole. In this case the seller should be furnished with a schedule giving the pole number and the height of the corresponding pole, together with such notes as will enable him to find about every fifth stake from local references familiar to him, such as farm houses, roads, etc., or from objects readily seen. With such a list he can deliver without further help from the buyer, but it is much better to have an inspector present. The work then moves faster, provided of course that the inspector knows the line in advance, and disputes and delays from errors are largely prevented.

Poles from outside and treated poles—of which more hereafter—are usually delivered on cars, and must be distributed. Treated poles should be framed before treatment. Other carload poles are best framed in the yard where they are unloaded. Indeed, framing is always best done in the yard, but where, as is usually the case with native poles, delivery at the hole is as cheap as delivery in the yard, this saving more than offsets the gain of yard framing. Where poles are field framed the arms and attachments are put on at the same time, making some saving here. But in a properly arranged yard there is no time lost going from pole to pole, and particularly if the poles are to be shaved, the derrick used for unloading makes a very considerable saving in labor.

It is still the practice, in many cases, simply to roll the poles off the car by hand after as many as can do so have fallen when the stakes are out. This, however, is dangerous to the men, is apt to break some of the poles, and necessitates much additional labor in rolling the poles into piles. A derrick, on the other hand, unloads with safety to men and materials in a fraction of the time, and places the poles where wanted, particularly if, as it should, it has a long boom. A derrick saves the cost of helpers

for the framers, and is usually invaluable in handling heavy material, other than poles, from cars to trucks.

A Good Inspector Would Have Prevented This. In order to determine whether the pole was a live cut it is customary to specify that the pole shall not be shaved. This is usually interpreted to allow knot and branch projections, although the latter are usually "to be trimmed close," so that quite a little draw-knife work is necessary after delivery. Following this, the butt is cut square, the top roofed, and the gains and faces made. In

Setting Poles by Car Derrick. A—Pole Hooked on, Horses Hoisting

firm soil the requirement of a square butt is not as essential as in soft soil, where it is very important.

The writer was once delighted with the speed with which a new foreman set poles—until a day or two later, when the cross-arms were apparently all that kept them from toppling over. The "villain" had sharpened the butts, dug a hole about a foot deep, wiggled the pole with the spikes after it was up, and moved on to the next!

The roof treatment depends somewhat on the attachments, for there are several special top pin fixtures requiring individual framing. If none of these are to be used, the most general prac-

tice is to form a wedge, although an almost equally common method is to sharpen to a point, the pitch angle in either case being about 45 deg. The wedge is usually set with the edge at right angles to the direction of the line, but where roof pins are employed and are doubled the edge should be parallel to the line.

Gains are cut of just the width of the arm, from ½ in. to 1 in. deep at the center. They should be slightly concave, so that the arm will bear on the edges, thus preventing rocking. With the best of care, however, it is difficult to get a good fit, and as the average "pole butcher" comes far from being careful, there have been developed several patent metal gains, which are lagged or spiked to the pole. These do not require cutting of the pole otherwise and give as good a fit to the arm as the dimensions of the arm permit, for crossarms are not always true to a hair.

Faces are required for many of the patent fittings, and for some that are not patented, for that matter. The shape is of course fixed by that of the contact surface of the fitting, but the face should be at least ½ in. larger all around, and like the gain should be hollowed a little to insure a firm bearing.

After the framing is completed, including the boring of holes for the bolts, all of the cut surfaces should receive at least one, and, better, two coats of some good preservative. If the pole is not to have butt treatment it should also receive at least a "belly band" or belt of preservative extending 1 ft. each way from what will be the ground line when the pole is set.

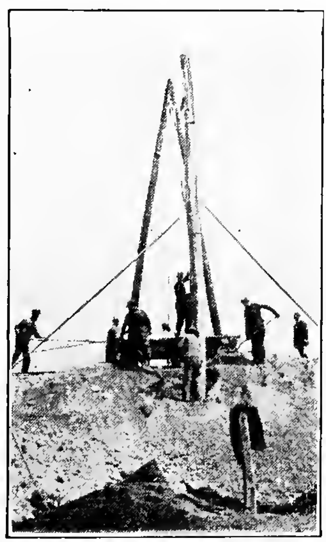
Some Minor But Important Points in Line Construction. If the pole is yard-framed the attachments will not be installed until the pole has been delivered at the hole. If it is field-framed they go on immediately after the preservative, and there are one or two little points that should be remembered in this connection. For example, bolts should be so driven that the nut is always next the attachment. No one who has ever tried to back out a bolt in order to replace an old crossarm needs to be told why, but there are many so-called "linemen" who do not stop to think of maintenance, and unless closely watched can cause much trouble later on.

The projecting ends of bolts should be cut off close to the nut. This is rarely done, but it should be the rule. With the best of judgment in getting materials and distributing them there will

B—Pole coming up bank

C—Pole nearly up

D—Pole in place and nearly lined



E—Pole lined hole being filled

SETTING POLES BY CAR DERRICK

be occasions when it is cheaper by far to use a long bolt on a short grip. The resulting end sticks out like a sore thumb and is a menace to the linemen's clothes if not to their persons.

Care should be taken that the fittings all make the same angle with the center line of the pole. Nothing makes a line look worse than a little variation in crossarms, brackets or other fittings that should line up. It is quite customary to install crossarms but leave the braces free until the poles are set to insure good line, but with reasonably straight poles practically as good results can be secured by completing the work on the ground.

Digging Pole Holes May Be Quite a Job. In ordinary soils digging the hole is a comparatively easy proposition, although it takes a little experience efficiently to handle the lower portion. An ordinary short-handled round-point shovel is much the best tool for the first 3 ft. or 4 ft., and if the hole is large enough for a man to stand in it and work it is best for the entire depth. For most holes, however, a long-handled round-point shovel and a spoon will be required from about 4 ft. on. A pick for the surface and a digging bar for the deeper portions are also needed unless the soil is soft and free from stone. Patent diggers are used in some instances, with varying success; in general they do not work as well as the usual shovel outfit.

Ordinarily conditions do not warrant the use of power diggers, but on a Western telephone line a gasoline earth auger is said to have been very successful. Unless the ground was fairly free of stone and unless there were a large number of holes the overhead cost would eat up all saving unless the time saved was worth the difference, particularly as the device would have to pay for itself on the job.

Sometimes It May Not Pay to Blast Out Rock. Rock is always a nuisance, and often considerably worse than a nuisance. In the open a heavy charge will often so shatter the rock that it can be readily taken out, but it is important that it is not merely cracked into large blocks, as these are very difficult to handle, while the blocks necessitate heavy charges further to break them up.

Where the rock is at the surface and is of good quality the pole may with advantage be set on the top and held in place by a special shoe stone-bolted down, or by three strap bolts set in holes 120 deg. apart on the outside edge of the butt. Such bolts

should extend at least 12 in., or better, 18 in. into the rock, and may be held by filling the space between them and the hole, which should be about ⅛ in. larger than the bolt itself, with melted lead, sulphur or Portland cement grout. In place of using one of these the end of the bolt may be split to receive a wedge which, when the bolt itself is driven down, jams the sides against the sides of the hole. It is hardly necessary to point out that, if lead or sulphur is used, the holes should be perfectly dry. A little moisture converted to steam by the hot material can throw a small amount of melted lead or sulphur over an astonishingly large area.

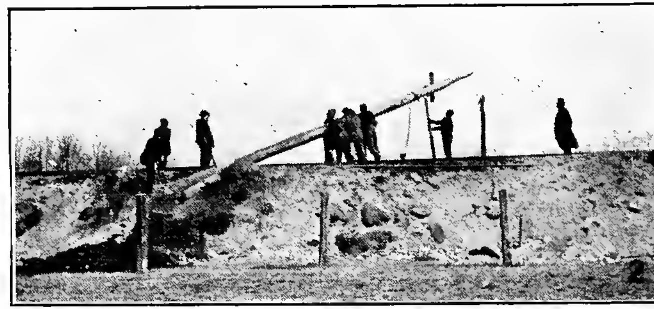
The upper ends of the bolts should be about a foot long, measured from the rock, and should be flattened and lagged to the pole. For poles up to 40 ft. high above the rock ¾-in. bolts will serve unless the line is exposed to heavy winds. In the latter case, and for higher poles the bolts should be of inch stock, and the lags should be about 6 in. long as against 4-in. lags for the smaller bolts.

Soft Ground Requires Reinforcing for Pole Support. Very soft material is often even harder to handle than rock. If they are too "quick" and if the poles are not too large, soft soils can be conquered with headless barrels, the hole being started as usual and the barrel then set in it and forced down as the material is taken out by the man inside. When the top reaches the surface a second barrel is set on it, three or four cleats inside keeping it in line. The bulge of the barrels and the poor connection usually limit the "string" to two, giving less than the proper depth just at the point where deep setting is needed. By filling the space between the barrels and the pole with concrete this difficulty is removed.

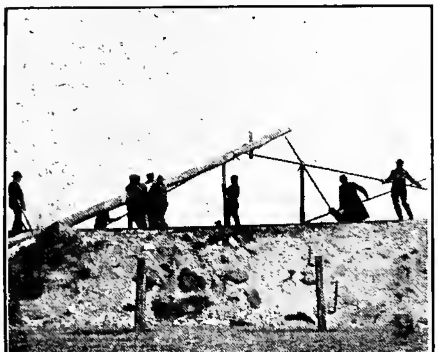
The hole may be dug inside of driven sheeting, in which case it will usually be made square for convenience. For this a square frame of 6-in. x 6-in. timber, having clear inside dimensions slightly greater than the diameter of the pole, is placed in position and a similar square with inside dimensions greater than the outside dimensions of the first by an amount about ½ in. more than twice the thickness of the sheeting to be used is placed outside it. The sheeting is then set up in the space between the braces and driven down as the excavation inside proceeds.

By sharpening the sheeting so that the cutting edge is at the

A—Lifting

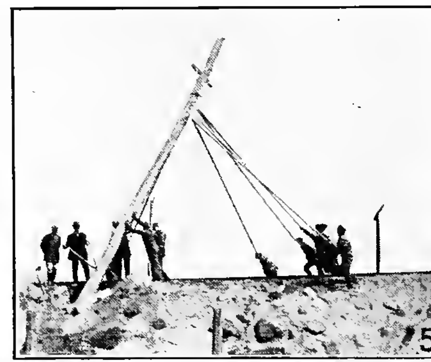


B—Ready for pikes



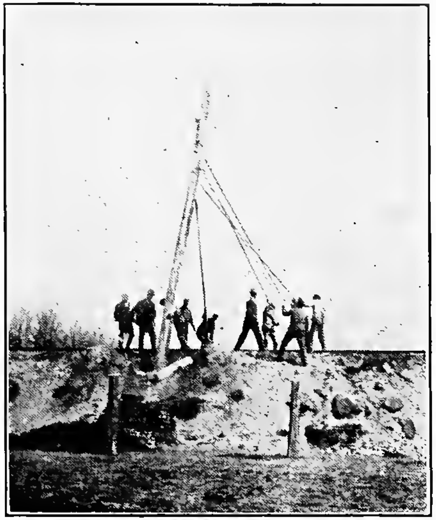
C—First pikers piking

D—All pike poles in, note butt man twisting his pole with cant hook

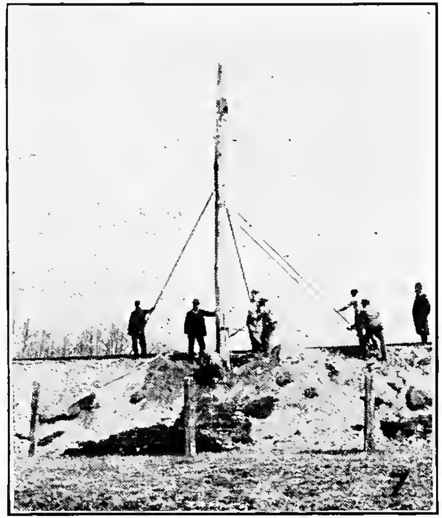


E—Jinny at end of its service

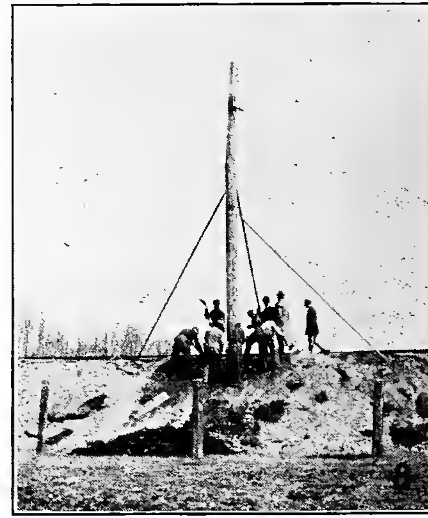
SETTING POLES BY HAND



F—Butt sliding into hole



G—Pikes grounded, butt man giving last twist before filling in



H—Pole in place and lined up, hole being filled

SETTING POLES BY HAND

outside and slants to a point on the edge next to the previous piece it can be kept fairly straight and tight, but additional bracing rings should be set inside every 3 ft. or 4 ft. If the hole is much more than 6 ft. deep it may be necessary to use a second set of sheeting, in which case the first set should form a square enough larger than the required hole. With 6-in. bracing and 1½-in. sheeting this would require 15 in. additional width and breadth in the top, the bottom inside ring of the first set forming the top outside ring of the second set.

If there are many soft holes, by far the best device is a steel cylinder in halves, of a length equal to the deepest hole required, and a diameter sufficient for the largest pole. The outside should be free from any projections, the clamps coming inside, and there should be two stout rings on each half. It is used just as are barrels, but after the pole has been set it is pulled out by tackles or jacks and taken off the pole by separating the halves. It is then ready for the next hole.

How Deep Should Poles Be Set? The question as to what should be the depth of setting has been answered in different ways by different people, but the values adopted by the American Electric Railway Association have been largely used. They are as follows:

Length of pole in feet	Depth of Hole: In rock or with concrete setting	Depth of Hole: In earth
30	5 ft. 0 in.	6 ft. 0 in.
35	5 ft. 6 in.	6 ft. 0 in.
40	5 ft. 6 in.	6 ft. 6 in.
45	6 ft. 0 in.	6 ft. 6 in.
50	6 ft. 6 in.	7 ft. 0 in.
55	6 ft. 6 in.	7 ft. 6 in.
60	7 ft. 0 in.	8 ft. 0 in.
65	7 ft. 0 in.	8 ft. 6 in.
70	7 ft. 0 in.	9 ft. 0 in.

In very compact soil values intermediate between rock and earth may be used, while if one-third or more of the bottom part of the hole is rock, rock values will be ample.

Economy in Man-Power Is Essential in Pole Raising. The poles having been framed and delivered and the holes dug, it remains to erect them. The good old-fashioned way is to pike them up by hand. A board is stood up at one side of the hole, and the pole brought up with the butt against this and resting

on a short piece of plank on the opposite edge. One man with a cant hook stands at the butt to keep it on the plank. Another holds the "jinny," which is a substantial prop of Y-shape about 7 ft. long. The rest of the gang lift the top, starting at the top and walking toward the butt as it rises, while the jinny man follows along to prevent any drop in case the men should slip.

As soon as the top is 8 ft. or 10 ft. above the ground the two first pikers "stick" it and lift as far as they can. The others in turn "stick" in pairs and lift, each pair moving in in turn and "sticking" again as the lift takes their point out of reach. Meanwhile the jinny man keeps his prop close against pole and ground as long as it is effective, which is until the pole is at an angle of about 60 deg. with the horizontal. As it approaches the vertical the butt man twists it if necessary to keep the arms properly lined. When fully up it is plumbed, or raked as the case may be, by the foreman, and then is held in position by grounding the pikes in a circle about it until the hole is well filled.

Chestnut poles require, roundly, as many pairs of pikers as one-third of the pole length in feet, together with one jinny man and one butt man for poles up to 45 ft. long. Two butt men are required for longer poles. Cedar poles are considerably lighter, and the gang for the shorter lengths may be reduced by a pair of pikers.

Mechanical Pole-Raising Devices Have Their Place. To-day, however, the tendency is to employ some form of mechanical setter, either in the simplest form, a gin pole, or, if the extent of the work warrants, a more elaborate form of derrick mounted on a car or truck and operated by hand winch, horse tackle or gasolene hoist. With these there will be required four laborers, a driver, or an operator, depending on the form of hoist, two men to hook on to the poles, one of them can also serve as butt man, and one or two pikers for lining up. For the shorter poles there is not much if any saving in number of men, the economy coming in the greater speed. For the longer poles there is a large saving both ways, and there is far less liability of accident.

If the pole is to be subject to heavy strain it is now "keyed" with wood, stone, or concrete, at least 4 in. thick, and with a cross-sectional area not less than 32 sq.in. One key, at least 2 ft. long, is placed on edge at the bottom of the hole on the side oppo-

site the anticipated strain; the other, 4 ft long, is placed on edge at the surface, on the side of the strain. At least, this is the case in firm soil; in soft ground the keys may have to be considerably larger, or the desired result may be secured by filling the hole with concrete.

Whether the re-fill is earth or concrete it should be put in in layers and well tamped. There should be at least three men tamping to one man shoveling, and the material should be piled up in a little mound around the pole both to shed water from it and to prevent the formation of a small pond by the settling which is sure to occur. If there are pieces of rock available these should be saved for the upper part of the hole unless needed to stiffen up a soft bottom. In the latter case it is often desirable to make a "pancake" or "biscuit" of concrete, 6 in. or 8 in. thick, in the hole.

If carefully lowered, a pole can be set on such a bottom in about thirty-six hours after the concrete is placed, but it is better to let the concrete set for a week. If it must be used sooner, a cushion of earth about a foot deep will help maintain the virtue of the green concrete.

CHAPTER XIX

SOME PRACTICAL POINTS IN POLE AND TOWER ERECTION AND SUPPORT

In the cases of pole settings described in a previous article it has been assumed that the soil is of reasonable bearing capacity, at least ½ ton per square foot. It is generally a very good investment to go around any area of softer ground that cannot be "jumped" by a long span. When, however, the difficulty must be met directly, special construction is required.

The simplest plan is to attach the poles to a trestle or bridge, but frequently there "is no such animal," and where there is one, if it is owned by other parties there is often refusal to permit its use, or a prohibitory rental is demanded. If the structure and the line are built at the same time, as is often the case where they are for the same property, it is a simple matter to provide for the pole attachment, but if the structure already exists it may be difficult to get clearance. Sometimes this latter is effected by leaning the poles outward. With pin insulators this tends to lower the wet weather resistance; with suspensions it may necessitate special construction to maintain the normal clearance.

Setting Poles in Soft Ground. When the line must stand on its own feet the treatment depends primarily on the character of the soft ground to be crossed. With open water, or in a swamp of some depth and lacking a firm top, practically the only possible treatment is to use piling, to which the pole is bolted either directly or through some intermediate structure. How to handle the piling is often a very serious question. It is surprising with how light a hammer a pile can be "worried down" into soft material, and with but a few inches of open water a light draft barge can be rigged up that will serve every purpose. It is of chief importance to give the piles holding power against a pull or push on end, for three piles which sway greatly at a touch, if

they have a batter of 3 in. or more to the foot, can be tied together at the tops to form an exceedingly firm support.

Where there are only a few poles to be driven, it is often possible to work them down by setting them in place, loading them as heavily as possible, and then, by means of several lines tied to the top with a man on the other end of each line, rotating the top in a small circle. There are two difficulties to look out for. So long as the motion continues the pile will go down, unless of course it has reached hard bottom other than sand, but if it is allowed to stand for a short time the material settles back and makes further "driving" all but impossible. The other point is the danger of an upset in the early stages if the load is very heavy and the head is pulled much out of plumb. This method can sometimes be used to advantage in the case of soft swamps which cannot be navigated by scows, but on the other hand are too soft to carry the pole on surface supports. Incidentally, it will often permit the putting down a pile or a pole in a sandy bottom under water which would completely resist driving by hammer unless a water jet was used.

Special Treatment Needed on Long Stretches of Marsh. It should, of course, be understood that these treatments are particularly for the cases where the stretches of bad ground are comparatively short, and separated from each other by some distance. If the adverse conditions are extensive the situation will warrant some study and often considerable investment in plant specially designed to meet the case.

Many swamps have firm bottom overlaid by "mush" of no stability whatever. Single poles rested on this firm base will be perfectly good against the load so long as they stand plumb, but unless their penetration into the hard material is practically to the depth which would be given in setting them on dry land, or other preventive treatment is given, they are very apt to sway badly in the wind and presently to overturn. Such poles may be steadied by guys, with concrete, stone or metal anchors, in which case the guys must be of such material or so protected as to guard against corrosion.

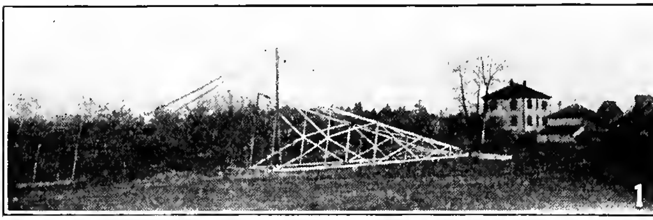
Of higher first cost, but usually much cheaper in the end, is the use at each pole of three piles, battered at least 3 in. to the foot, 120 deg. apart and projecting about 8 ft. above normal water level. At their tops these are bolted to the pole, the butt

of which rests on and is bolted to a framework carried by the piles just above water level. An experienced crew finds little difficulty in driving batter piles, though the pile driver may not have been built for such work, but where the men are all green a plumb structure may be used, the piles forming a triangle or square about 12 ft. on a side. In this case the piles should extend roughly one-third of their length above the water and the adjacent ones should be tied together by X-bracing for this length to prevent swaying. The pole may be carried as in the case of the battered triangle, or it may rest on the top platform and have braces from the pile tops to a point near the bottom crossarm.

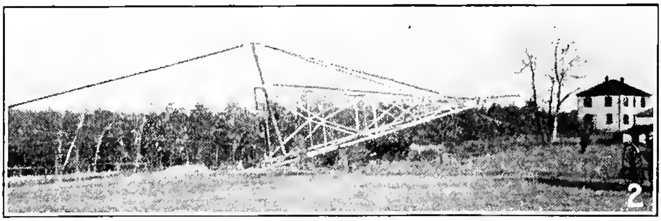
Some Meadows Are Particularly Treacherous. Morasses of the open water type are obviously danger points, and while their treatment may require quite a little study they are not at all likely to be overlooked.

"Cats of entirely different color" are the meadows with a more or less firm top covering all sorts of iniquity. If the crust is thin the treacherous character is fairly evident, but when, as is often the case, the crust is firm to a depth of several feet, it is easy to make the mistake of supposing that the firmness holds all the way down, with consequent later regrets. Swampy character of the surface and the presence of black or brown soil are always a warning to test with a sounding rod. For pole-line purposes a few short lengths of ½-in. steel pipe with a solid point to screw on the end are excellent. With a solid surface 3 ft. or 4 ft. thick, a pair of sections of old pole 8 in. or more in diameter and 8 ft. or 10 ft. long, or their equivalent (a pair of railroad ties are excellent), bolted through the center to the pole at ground level, will give the necessary additional support. For thinner crusts the bearing area needs to be correspondingly increased. Specifically, the probable maximum dead weight is that of the pole, the attachments and the half spans each side, with the ice load for the district. The area of support must be such as will give a pressure per square foot on the surface covered not over one-fourth the pressure the surface can stand.

What that pressure may be can be roughly determined by loading a 6-in. x 6-in. stick held vertically by small guys. The weight which forces this through the crust is approximately the pressure allowable per square foot. In making such a test,

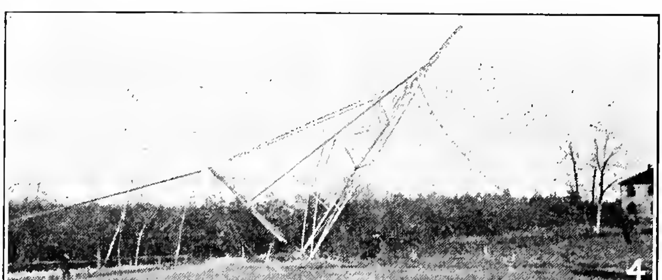


1—Ready to Start



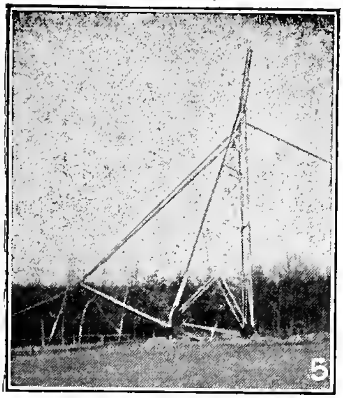
2—Tower Being Lifted, Gin Pole Acting as a Lever

3—Gin Pole Practically at the End of Its Duty

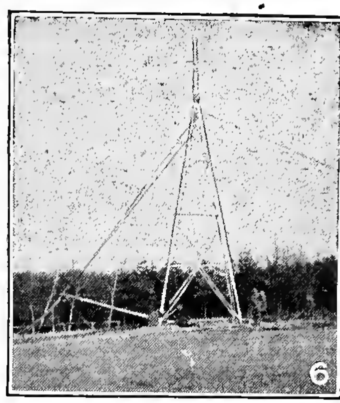


4—Gin Pole Pulling Away as the Attachment at the Top Gives Greater Leverage

Successive Steps in the Erection of a Transmission Line Tower



5—Holding Back the Top While a Man Adjusts the Foot Connections



6—Tower Up, Foot Connections Being Bolted Up

SUCCESSIVE STEPS IN THE ERECTION OF A TRANSMISSION LINE TOWER

enough time must be allowed to bring out the facts. Marsh crusts will usually carry for a short period a load much in excess of that which would break through in a longer time. A fair procedure is to add 50 to 100 lb. each time, and to allow three or four days to elapse between successive additional loads. If, however, time does not permit this, daily loads of 200 lb. each will give fair indications, and will be on the safe side.

The purpose of the support arms is particularly to give support to the vertical load, and whenever practicable guys should be used to prevent overturning. The crust of a meadow owes its strength very largely to the network of living roots of the plants growing on it and, like a piece of cloth carrying a load, fails badly as soon as any break occurs in the fabric. If support arms are relied upon to take the place of guys, the pole, tending to turn at the ground line, throws the entire effort on the end of the arm. This gives a pressure which is equal to the bending moment of the pole at the ground line in pound-feet divided by the distance from the pole to the end of the arm in feet. (It will be remembered that the bending moment at the ground line is the sum of the resultants of each element of pressure multiplied by its distance above the ground line.)

This arm pressure tends to force the end of the arm into the earth, increasing the area pressed, and at the same time to lift the pole bodily, the arm end acting as a fulcrum, until the forces

balance. The fulcrum can be given sufficient area to bring the pressure per square foot within safe limits by putting cross timbers or mudsills under the arm ends. But in choosing these the cross-section must be not only strong enough to transmit the load from the arm to the surface without breaking when new, but must have a large factor of safety to cover the reduction of strength which is apt to be rapid because of the conditions.

Where the arms are depended upon for cross-line support, they will usually be 3 in. x 8 in. or larger, in pairs, through-bolted to the pole, which should be slightly flattened to give a good bearing. Paired diagonal braces, 2 in. x 6 in. or heavier, and making an angle of 60 deg. or more with the horizontal, have their tops through-bolted to the slightly flattened sides of the poles. The lower ends go between the arms close to the ends and are there bolted, a block of the proper thickness being used to fill any space left between them. The bottom of the arms should be about 1 ft. or the thickness of the mudsills, if these are used, above the meadow surface, and particularly if arms or braces are less than 4 in. wide filler blocks should be bolted between at intervals of about 5 ft. All parts of these frames, as well as the pole to a point above the upper brace attachment, should have some form of preservative treatment, and particular attention must be given surfaces in contact and to holes or cuts made after treatment, to insure that they are properly closed.

Sometimes 1-in. or 2-in. plank is driven under and at right angles to the mudsills. It is a question, however, if this really protects the bottoms of the mudsills proper from decay, and if the latter are not of uniform thickness they are worse than useless until the uneven pressures are balanced, this generally occurring by breaking the heavily loaded planks.

In the long run it will almost invariably pay to use piling for the support of the ends of the arms, in which case the latter are framed and through-bolted into the piles. Good results, however, may be had with mudsills, which should be 6 ft. to 8 ft. long, with a vertical thickness of at least as many inches as the length in feet.

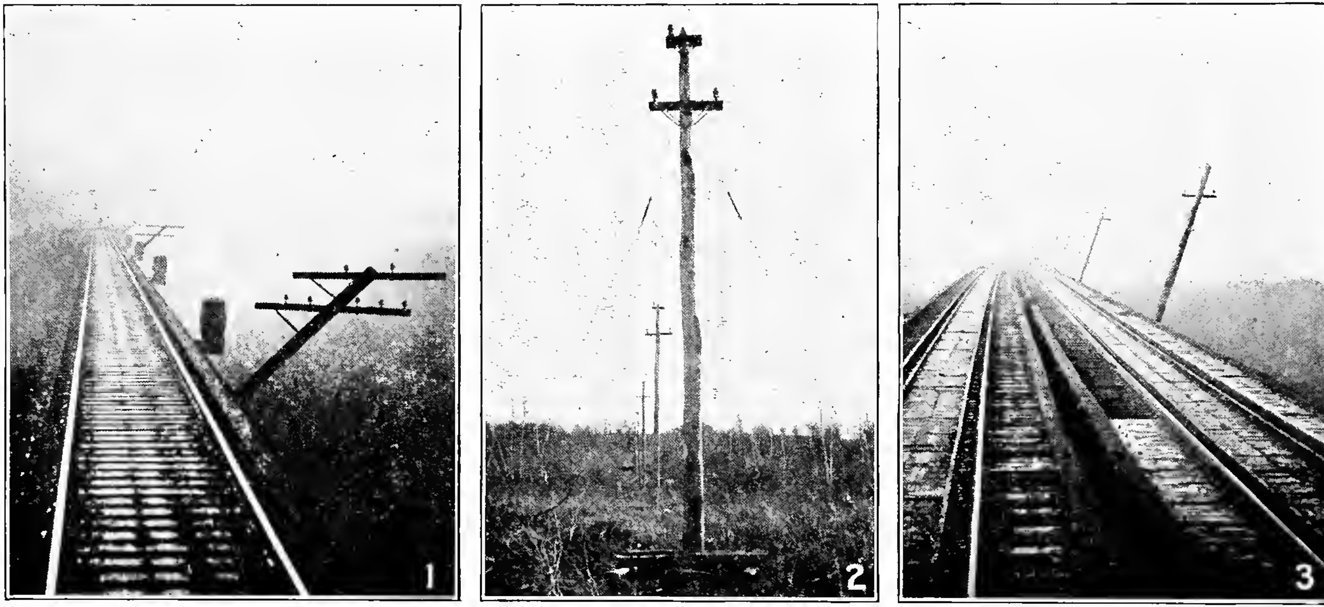
Concrete poles in firm soils are set to about the same depth as wood poles, but their weight and the impossibility of using ordinary pike poles practically compels the use of a derrick. In moderately soft earth a concrete footing is used, a plain or re-

inforced slab of sufficient strength to carry the weight of the pole and its loads being first cast in the bottom of the pole. If practicable, this is allowed to set for at least ten days before the pole is placed on it. The writer has not had personal experience with concrete poles used in very soft ground, but it would seem that conditions which warranted the use of a concrete pole line across such territory would also warrant the use of piles and brackets similar to these for wood poles but in reinforced concrete.

Steps Involved in Putting Up the Steel Tower. Tower erection usually involves three steps: placing the footings, assembling the tower and, finally, erection proper.

The early towers followed windmill practice, and employed masonry or concrete footings extending from below the frost line to at least 6 in. above the surface, and carried anchor bolts by which the tower base plates were held rigidly in place. The top, for an area of that of the base plate, was level with edges beveled to shed water. Footings of this type are still used for anchor and other special towers but require much accuracy in location. For the smaller towers, because of the large *relative* amount of forms and the small amount of concrete, they are very costly. Where they are used a "wrinkle" from steam-engine practice can be borrowed to advantage. Instead of placing concrete close around the bolts, a piece of tin rain leader of diameter 2 in. or 3 in. larger than the bolts, and of proper length to reach to the top of the footing, is slipped over each bolt, resting on the big washer at the bottom. The bolts, with these sleeves centered on them, are then hung from the templates and the footings are poured. The tops of the bolts can then be moved to meet any lack of agreement between tower base and template up to the limits of the large hole in the concrete, which is grouted full after the tower is bolted down.

The next step was the substitution for the base plate of the tower and the anchor bolts, of an extension of the tower legs to which the tower proper was spliced. At first this extension was bedded in the heavy form of footing, but very soon the latter was cut down to a sort of mushroom anchor. On at least one good-sized line these were cast in yards and after curing were teamed to the points of use. While this effected a large economy in labor costs it was found that unless the coating was reinforced,

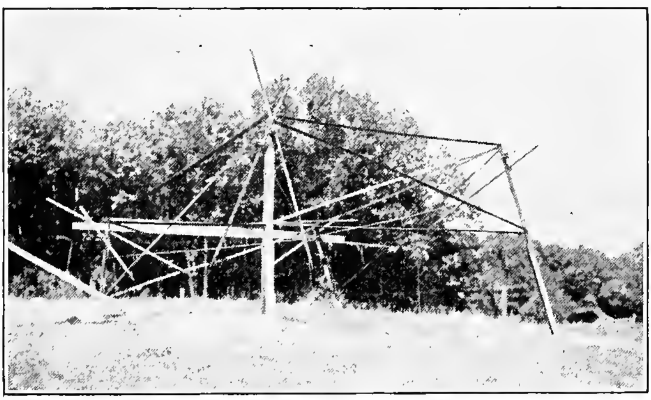


1 and 3—Poles Attached to Trestle and Inclined Outward to Secure Stability. 2—Pole in Swamp with Tie Supports at Base

in which case the saving was largely lost, it cracked off in handling.

To-day for good soil it is very general practice entirely to omit the concrete. The ground stubs, as they are generally known, consist of about 8 ft. of the section used for the tower leg, with a crossbar about 3 ft. long at right angles to it on the bottom. This stub should be protected with a heavy galvanizing or other treatment, although many are actually set with only the shop coat of paint.

Do Not Neglect Proper Refilling of Foundation Holes. It is essential that the refilling be of good material, preferably with some heavy pieces of rock on top of the crossbar, and if the setting is carefully done no difficulty need be feared. There occurred, however, a very costly failure on a Western line as a result of poor judgment of material. The line in question



Template for Setting Tower Footings

Note Paired Support at Each Leg, Now Lifted, on Which the Template Is Adjusted Before the Footings Are Set

crossed a flat valley having a soil which, while very hard when dry, lost all strength when wet. The holes, dug in dry weather, were blasted out, and the hard lumps were used as filling without ramming. When a little later a heavy rain flooded this low land, the lumps melted down like soaked sugar, and a long stretch of line went down, tower after tower, merely from the pull of the conductors.

Pre-cast foundations and ground stubs are usually set by tem-

plate. One of the best forms consists of a square or rectangle, having at its corners short sections of the same angle as is used for the tower legs and at the same inclination, together with a pair of rods or pipes in clamps. The angle sections are drilled as are the tower legs, and extend such a distance below the sides of the reetangle that the tops of the sides are an even number of feet below the lowest conductor, while from diagonal braees is hung a plumb bob at the center. The template is eentered on the tower center by the bob, squared with the line by center marks on the two sides, leveled at the proper height and supported on the adjustable rods. The template shown in the accompanying ent has pointed rods, which have to be well driven to prevent later

PRE-CAST MUSHROOM TYPE FOOTINGS
Note How the Concrete Has Broken off in Handling

settlement. A flat foot about 6 in. square is better but, of course, in such case care must be taken that the material beneath is reasonably firm and that any moss, leaves or the like have been removed. Ineidentally, flat-footed supports readily permit the recentering and relining which is almost invariably necessary after leveling up. The footings are now bolted to the template legs, the holes for them having been dug before the template was set. The holes are then filled in and tamped, keeping the refill at about the same stage in each hole and working completely and uniformly around the stubs to avoid springing them out of place.

By having the sides of two overlapping parts suitably drilled, the size of the rectangle can be adjusted for a very considerable range of tower heights, while the substitution of leg sections with base plates properly drilled makes it available for such foundations. In the best form of base plate the anchor bolt passes through the base plate proper and extends up through a second plate or bracket nearly a foot above, thus obviating the tendency to bend the bolt in the threaded portion, and this long bearing in the template holds the bolt against displacement as the concrete is poured. If the base is of the older type, in which the bolt extends only 2 in. or 3 in. above the top of the concrete, it will pay to have temporary extensions, readily made from heavy pipe, to screw onto the bolts, and fitting in guides on the template to hold them firmly in place. As they are vertical, they can hang from the template without such control and if sufficient care is taken there will be no trouble. With the bolt firmly held, however, displacement is practically impossible except by deliberate intent, and the insurance is well worth the trouble.

Towers Are Usually Tipped Up into Place Complete. Although there is pretty wide diversity in tower design, the shipment, assembly and erection of the types differs comparatively little. The flexible forms are usually shipped complete, and rigid types are shipped knocked down, the parts for each tower together. Bolts and small parts are bagged; other members are tied in bundles. Each bag or bundle is marked with the tower number and the nature of its pieces, and each piece with its erection mark. It is therefore a simple matter for the checker to make sure that, barring a shortage of parts in a bundle, all the material for any tower is on the ground.

The assembly gang, following the men setting foundations, usually set up opposite sides flat on the ground. They first lay out the two adjacent legs the distance apart they will be and at the angle they will make when assembled, with the bottoms close to the foundations, then set the other leg of each side and finally put in the diagonal. In the case of those towers which, like the Milliken, have legs which are pyramids, the entire half tower can be so erected. With towers having long connections from leg to leg only the sides are first set up. The parts are then turned on edge and the assembly is completed. Moderately high

towers are often put up in two sections; heavy towers are almost always erected piece by piece in place.

The earlier method of erection was by some form of gin-pole or derrick which lifted the tower bodily into place, but to-day the practice of tipping it up on its base is almost universal. Certain designs have the necessary stiffness; for the others temporary wooden braces are fastened between the legs. A cable is then made fast near the top of the tower and to the top of a tilting pole set up at the tower base. This pole is about one-third as long as the tower height and, in addition to the cable back to the tower top, it has fast to its top the hoisting falls which lead to an anchorage about the tower's length from the foundation. A hold-back from the tower top to a good ''snub'' or anchor completes the rig.

When all is ready two men ''stand by'' at the foundation and one at the snub; a pull on the falls tips down the top of the tilting pole and through the cable tilts up the tower until falls and cable are in the same line. After this the tilting pole simply hangs on the line and the pull is directly on the tower. As the latter comes near the vertical it is checked by the snub until what have been the upper two legs can be connected to their stubs by one bolt each. The tower is then rotated on these bolts as pins until the other legs can be connected to their footings, when all are bolted up. With foot-plate foundations, if the tower is tilted up it is necessary to put blocking to the level of the bolt top and then to lower the tower after it has been lined up. General practice, however, confines foot plates to towers which are built in place or to those which, as when along a railroad or highway, can be handled bodily by a derrick. Where free access can be had to the foundations a truck or car derrick is by far the best device for erection. As a rule, however, much of the line comes where a derrick cannot be readily taken. The labor of handling and guying a gin pole of sufficient capacity makes it less economical than tilting pole.

Towers so heavy as to require piece by piece erection follow ordinary structural steel erection practice with riveted connections throughout. The smaller towers—except the A-frame or flexible type, which are usually riveted in the shop—are almost invariably bolted together.

CHAPTER XX

DETAILS OF LINE CONSTRUCTION, WITH PARTICULAR REFERENCE TO GUYING AND ANCHORS

We have seen that a pole must carry the dead load of half of each adjacent span, the unbalanced portion of the pull of the conductors along the line, and the cross-strains resulting all along the line from the wind, and at the angle points from the conductors; further, under special conditions it may have a vertical pull downward, or more rarely, upward. If the soil is firm the poles of the average line will carry these strains, but the possibility—and in most instances the probability—of ice storms or of heavy winds, if not both together, make wise the use for insurance if they are not actually necessary, of some form of additional support on the tangents as well as at the corners, and this is usually obtained by braces or by guys attached to some form of anchorage.

The Old Reliable "Deadman" Is Widely Used. The oldest and one of the best forms of anchor is the good old deadman, which has been in use for various purposes for a long time. In its simplest form it is buried in a T-shaped trench, the stem pointing at the pole to be guyed. The head trench, from 4 ft. to 6 ft. long, is cut vertically to a depth of from 4 ft. to 8 ft. depending on the length of the anchor rod and its angle when in place. The stem starts at the head with a depth about 1 ft. less, and slopes up on the angle of the finished guy to meet the surface. The "deadman," a log, tie, concrete or stone bar, or a platform of plank, lies in the head trench with the anchor rod passed through its center and pointing in the line of the guy. Where the material is available the deadman is first covered with heavy pieces of stone and then the rest of the excavation filled and well rammed. In those cases where existing obstructions or the liability of disturbance from adjacent excavation make the T-form inadvisable the deadman is laid parallel to the pull. In this case it is particularly important that the refilling be

well done; the material should be puddled in and allowed to drain out before the anchor is used.

By far the commonest form of deadman is a log which is usually from 4 ft. to 6 ft. long and from 6 in. to 1 ft. in diameter, although for railroad lines the use of a half or a whole tie is quite general. If sound when installed these, even without preservative treatment, will last indefinitely in wet ground, and elsewhere they usually will outlast the anchor rod. Treatment, however, is not expensive and is good insurance. The "real thing" in the way of a permanent deadman is a cross-bar of the proper size, of stone or of reinforced concrete. If the anchor rod is properly protected also, the construction is probably as nearly absolutely permanent as can be had, but while such treatment may be warranted for the anchors of flexible towers or for poles of the Gibbs-Hill type of electrification, the increased insurance over a wood anchor is rarely worth the higher cost in the case of ordinary lines. In very soft ground or in water, however, a concrete anchor which depends upon its own weight rather than that of the material above it may be absolutely necessary.

For moderately heavy service short lengths of creosoted plank are often used. The telephone standard is 2 ft. long, 1 ft. wide and 1 in. thick with a central hole; two lengths, held at right angles to each other by two ten-penny nails, being used together. For heavy service, when logs of proper diameter cannot be had, a narrow log is sometimes made effective by placing such planks across and in front of it.

The log, plank or other more elaborate form of deadman, is connected with the guy by means of an anchor rod, ⅝, ¾ or 1 in. in diameter and 6, 8 or 10 ft. in length, with nut and heavy washer. The latter is usually 3 in. by 3 in. and 3/16 in. thick for the first two diameters of rod, and 4 in. x 4 in. and ½ in. thick for the 1-in. diameter. The upper end is an eye. All parts are galvanized or sherardized. There is on the market a rod ½ in. in diameter, but while this when intact has sufficient strength for most services, a little corrosion reduces its capacity to a dangerous point and the small saving in first cost is soon lost. In the case of a concrete or stone deadman the washer and nut should be covered with at least 1 in. of concrete, and the rod should be cased in concrete to a point at least 6 in. above the ground.

The strength that a given deadman will develop depends upon the character of the soil, the angle of pull, and the care with which it has been installed. With a directly upward pull the tendency of a buried log is to lift a chunk of earth consisting of a wedge-shaped body with half cones at the ends. The body has the same length as the log and the sides slope out at an angle, depending upon the character and condition of the soil. It is customary to assume a vertical pull, although this rarely is imposed, but so far as the writer is aware there have been no experiments to determine the effect of the inclination of the anchor

Example of Long-Lead Guying, C. M. & St. P. Electrification Near Three Forks, Mont. Slope of Guy, 1 to 1

rod which where practicable should be 45 deg. from the horizontal, but is more often greater.

On the supposition that the wedge slope would have ½ ft. of base for each foot of depth, that the log is 1 ft. wide, and that the earth weighs 100 lb. per cubic foot, we get, for various sizes and depths of burial of the log, the capacities set forth in Table I.

The American Telephone & Telegraph Company has standardized on five guy materials known by their nominal breaking capacities as: 4000-lb. wire, 4000-lb. strand, 6000-lb. strand, 10,000-lb. strand and 16,000-lb. strand. The anchor system of this company is based on the last three of these guy materials as in

TABLE I—HOLDING POWER OF LOG DEADMEN

Depth of Log Below Surface, Ft.	Length of Log in Feet				
	1	2	3	4	5
	Holding Capacity in Pounds				
5	5,600	7,400	9,100	10,900	12,600
6	9,000	11,400	13,800	16,200	18,600
7	13,400	16,500	19,700	22,800	26,000
8	19,100	23,100	27,100	31,100	35,100
9	26,200	31,100	36,100	41,000	46,000
10	34,800	40,800	46,800	52,800	58,800

Depth of Log Below Surface, Ft.	Length of Log in Feet				
	6	7	8	9	10
	Holding Capacity in Pounds				
5	14,400	16,100	17,900	19,600	21,400
6	21,000	23,400	25,800	28,200	30,600
7	29,100	32,300	35,400	38,600	41,700
8	39,100	43,100	47,100	51,100	55,100
9	50,900	55,900	60,800	65,800	70,700
10	64,800	70,800	76,800	82,800	88,800

TABLE II—A. T. & T. CO. GUY ANCHOR DATA

No. of Guys per Rod	No. of Rods per Anchor	Kind of Strand	Anchor Rod	Kind of Anchor	Dimension of Log	Depth of Log
1	1	6,000	⅝ in.	Plank, log, or patent	5 ft. x 10 in.	6 ft.
2	1	6,000	1 in.	Log	6 ft. x 15 in. or 7 ft. x 13 in.	8 ft.
1	2	6,000	⅝ in.	Log	6 ft. x 12 in. or 6 ft. x 10 in.	6 ft. 7 ft.
1	3	6,000	⅝ in.	Log	6 ft. x 18 in. or 8 ft. x 12 in. or 10 ft. x 12 in.	6 ft. 7 ft. 6 ft.
1	1	10,000	¾ in.	Plank or log	6 ft. x 12 in. or 6 ft. x 10 in.	6 ft. 7 ft.
2	1	10,000	1 in.	Log	6 ft. x 15 in. or 7 ft. x 13 in.	8 ft.
1	2	10,000	¾ in.	Log	6 ft. x 18 in. or 8 ft. x 12 in. or 10 ft. x 12 in.	6 ft. 7 ft. 6 ft.
1	1	16,000	1 in.	Log	6 ft. x 15 in. or 7 ft. x 13 in.	8 ft.
1	2	16,000	1 in.	Log	8 ft. x 15 in. or 9 ft. x 13 in.	8 ft.

TABLE III—COMPARISON OF A. T. & T. CO. DATA WITH THOSE OF TABLE I

A. T. & T. Co. Log Size	Depth Buried	To Hold	Capacity by Table I	Safety Factor
6 ft. x 12 in.	6 ft.	2 at 6000 lb. or 1 at 10,000 lb., say, 12,000 lb.	21,000 lb.	1.75
8 ft. x 12 in.	7 ft.	3 at 6000 lb. or 2 at 10,000 lb., say, 20,000 lb.	35,400 lb.	1.77
10 ft. x 12 in.	6 ft.	3 at 6000 lb. or 2 at 10,000 lb., say, 20,000 lb.	30,600 lb.	1.53

Table II. The Western Union Telegraph Company has a very similar practice, but lists more log sizes and includes for use with them anchor rods of ½ in. and ⅝ in. diameter. Comparing these figures with the data of Table I, we have the data of Table III.

As the telephone practice has long proved its sufficiency, it is very probable that anchors in average soil will develop at least the strengths given by Table I, but in view of the importance of an anchor, and, in most cases of the small additional cost of another foot of burial it is altogether wise to be liberal in allowances.

In the case of very heavy strains care must be taken that the deadman has sufficient body to prevent breaking at the rod, and that the washer area is large enough to prevent crushing the log. In all cases it is essential that the washer be seated on hard wood so that it will not "crush in" under the first strain and put slack in the guy.

Some Ingenious Anchors Have Been Devised. The installation of a deadman involves quite a little excavation, which in turn requires labor. The disturbance resulting frequently furnishes grounds for objection to a location, particularly in those unhappy cases where the right-of-way is too narrow and the abutter is not enthusiastic over the opportunity to assist the company. To obviate these difficulties a number of patent anchors have been developed. These are of various grades of excellence, all having been devised to secure installation with a minimum of disturbance and to utilize the fact that undisturbed soil has far greater holding power than that which has been disturbed.

Of the several types the screw form, which is one of the oldest, is a section of a helix on a rod which is screwed into the ground by means of a handle detached after the anchor is in place. In ordinary soil it starts without coaxing. In hard soil it is wise to make a leading hole by driving a crowbar in the direction the rod is to go and then pulling it out. The workman should stand on the blade until it has entered the soil. In dry soil a little water poured in the leading hole is a great help. Anchors of the harpoon type have wings which lie along the shank while the device is driven down with a sledge and are then opened by a pull on the shank. Like those of the screw types these require

no digging, but they are open to the criticism that unless they are fully opened they may complete the movement later and put slack in the guy.

The Bierce, Miller, "Everstick," "Hercules," "Never-Creep" and similar types require the excavation of a hole, but so small that it can readily be made by an earth auger or a special tool. The Bierce anchor is an inverted cone which, under pull, expands the broken stone immediately over it into the walls of the hole after the fashion of an expansion bolt. The Miller anchor consists of a metal plate, hinged at its center to the rod, which

Short-Lead Guys on Heavy Work, N. Y., N. H. & H. R. R. Near New Haven, Conn.
Note Guy Plates and Guy Hooks at Pole

is set in a hole the upper part of which has a diameter equal to the width of the plate while the bottom is bored out by a special tool to take the plate lengthways. The latter is pushed down lying parallel to the rod and is then turned at right angles when in place. The "Everstick" anchor is of the expanding type, but the blades move at right angles to the stem, eliminating the backward pull of the harpoon type, but on the other hand requiring a hole, which the harpoon does not. The three types just described have the hole in the line of pull; the "Hercules" and

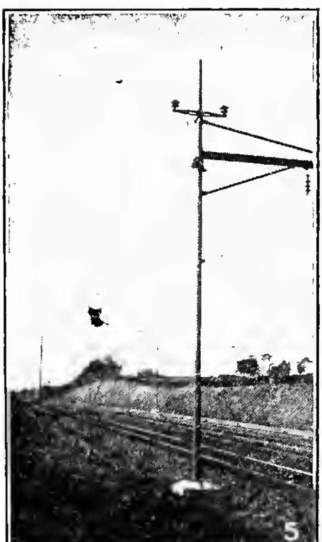
"Never-Creep" anchors have the hole at right angles to the line of pull. In the first form the rod takes its position in a channel cut from the main excavation. In the latter form the rod at the proper angle is driven from the surface until it projects into the hole. Then the plate, which has an enormous keyhole in it and is held by a special carrier rod, is slipped over the rod and down till the narrow part of the keyhole locks against the head.

All of these patent anchors have certain advantages over the deadman, and all have their faults, some more than others. Their one absolutely necessary requirement for successful installation is a soil reasonably free from large stones. An occasional "bone" can be dodged by shifting the location, but where such shifts are frequent it pays to set deadmen. The large trench necessary gives opportunity to deal with any kind of rocks that may be encountered nearer the surface than the proper position for the log. If small, such rocks can be removed; if they are of sufficient size, however, the obvious procedure would be to use them as anchors by installing "rock bolts."

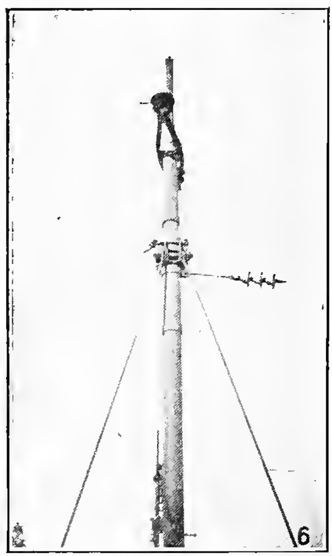
If the rock is tough, a suitable "rock bolt" would be a pair of wedge-shaped side pieces with bolt holes at the top, which are dropped into a tapered hole in the line of the pull of the guy and are held against the walls of the hole by a key fitting between them. This in turn is prevented from working out by a bolt through the tops of the wedges, to which bolt the guy is attached. The extra work of making the bottom of the hole larger than the top is more than offset by the fact that its depth is but 6 in. as against 15 in. for the other type. Although a standard article the wedge bolt is comparatively little used even in rock which, having the necessary strength to withstand its splitting tendency, is, by reason of that same fact, particularly costly to drill for the commoner type. The common type of rock bolt is a rod 1 in. in diameter, with an eye in one end. Although sometimes made with roughened sides, or with the lower end split to take a wedge which rests against the bottom of the hole and jams the parts of the shank against the sides of the hole when the bolt is driven down, the standard form, which is 18 in. long over the eye, is perfectly plain. As the bolt is set at right angles to the pull of the guy, the sulphur, lead or cement used to secure it in place really has very little strain to meet. If sulphur or lead is used, it must be melted at the hole, requiring some form of heater.

A push brace—good angle but poor framing

A study in bracing—replaced later by tower structure

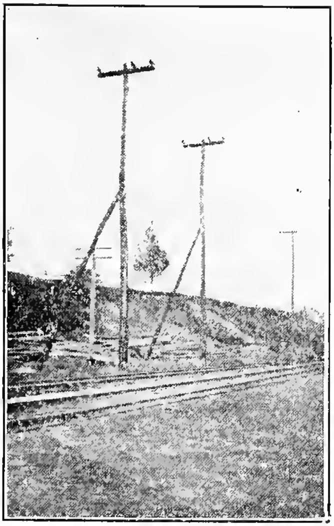


Heavy rod guys with turnbuckles and special casting for attachment to pole, P. R. R., Philadelphia-Paoli electrification.

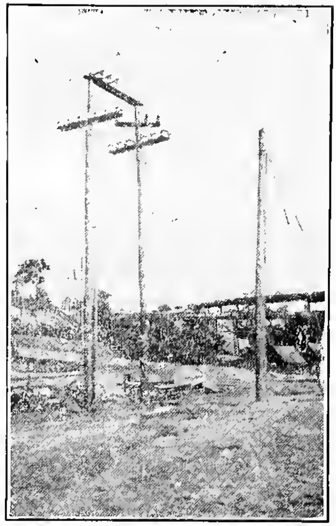


Special fitting for guy attachment, Philadelphia-Paoli electrification.

EXAMPLES OF SPECIAL SOLUTIONS OF BRACING AND GUYING PROBLEMS



Brace and guy work to prevent crossing railroad with guys



Stubs to give driveway clearance, New Milford, Conn.

Marsh work, braced bog shoe and guys, N. Y., N. H. & H. R. R. signal cable, New Haven.

Guy insulation wood strains on 11,000-volt line, involving the use of one 15-in. strain per guy.

GUYING AND BRACING POLES TO TAKE CARE OF UNUSUAL CONDITIONS

Care must be taken that there is at least 1/16-in. clearance between the bolt and the sides of the hole all around. The material must be poured at as high a temperature as is safe; in fact, it is a good plan to also heat the shank of the bolt but not enough to injure the protection on the portion which will be exposed. This is to prevent the filling from "freezing" before it has completely filled the space. Incidentally, it is exceedingly important that the hole be dry, for a very little moisture, to say nothing of water in any quantity, trapped under the hot material, will blow out the latter in every direction, with very good chances of putting an eye out of business. Cement grout of the consistency of thin cream is free from these disadvantages, requires no apparatus other than a tin can in which to do the mixing, and holds as well as the others. Further, the hole can be practically the same diameter as the bolt.

The best method of installation is to pour enough grout (2 in. or 3 in. depth being enough in most cases) in the bottom of the hole and then slowly to force the bolt down into place. Undue haste in this process is apt to produce a fountain of grout which, while not so dangerous as melted sulphur or lead, is not calculated to please the fellow who is hit. The only disadvantage of this method is the occasional difficulty in getting water, which may have to be "packed in." It is hardly necessary to point out that the grout should be made in the open and then put into the hole, although the writer has been told of an instance where a series of rock bolts were put in their holes, dry cement was packed around them, and then a little water was poured on top in the expectation that it would set up the entire packing. As a matter of fact, although only the very top of the cement did set, the bolts held all right and the peculiarities of the method were learned of only long afterward. In this case the pull of the guys was at a little more than a right angle to the holes, so the tendency was to pull the bolt in rather than out. In any such case a sharp sand filling reasonably well tamped in would have served as well. Indeed, if the pull is against the hole, no filling at all would have served as well as the cement, and would save its cost, but it is hardly the best treatment.

The guy itself is attached to the anchor rod, whatever the type of anchor, by an eye formed around a galvanized or sherardized thimble. At one time the usual method of securing this attach-

ment was by wrapping the end around the standing part (which as all know is the part of a rope or strand on the side of a loop opposite to the end) strand by strand, unlaying one strand down to the eye and then wrapping it tightly around the rest of the end (which is held parallel and close to the standing part) and the standing part; then unlaying another strand down to the wrapping and wrapping it on in turn, and so continuing until the last strand wraps around the standing part alone. While this, the "close tie," is considered by many as less likely to slip than the three-bolt clamp tie, this belief is due largely to the action of clamps of poor design.

Guy insulation, porcelain strains, double

Guy markers on 11,000-volt line, C., M. & St. P. electrification, Three Forks, Mont.

Properly made, the latter tie, which is now the standard of the telegraph and telephone companies, the N. E. L. A., and the A. E. R. A., will hold "until the cows come home." With it, even if the clamp is not properly bolted up either through carelessness or a faulty clamp, the resulting slip tends to twist the latter and kink the strand, so stopping the slip, although the appearance of the guy is spoiled Such slips, aside from failures to bolt up properly, are usually due to weak section, allowing the sides to buckle without putting sufficient pressure on the strand, or to the use of too large or too smooth grooves in the

clamp. Proper distribution of the metal will prevent the first, while the second is overcome, at least for use with ordinary strand, by making the grooves wavy or of variable width. If extra strength strand is used, however, special grooving to fit the twist is usually necessary to develop the full strength.

The three-bolt clamp is of low cost as compared with the material with which it is used, but it is a pretty important member of society. It has been well standardized, and the product of any of the responsible makers of line hardware can be depended upon fully. There is, therefore, little excuse for buying any of the nameless material which unfortunately is on the market at a price just enough lower than reliable material to attract a thoughtless purchaser—and later cost his overhead men their piety. The tie itself is made by bringing the end parallel and close to the standing part, installing the clamp close up if on a thimble end, or about 15 in. away from a pole, stub or similar large attachment, and securing the end, which should extend about 1 ft. beyond the clamp, by some ten or twelve turns of No. 12 wire about 1 in. from the extreme end.

Most clamps are variations of the standard three-bolt clamp, but there are two which are quite different. The Crosby clip, two short spirally-scored drop forgings clamped together by a U-bolt, is sometimes used for light work, but it is not often employed otherwise. The equivalent in "Crosbys" to a three-bolt clamp is at the very least two, with four parts and four nuts to adjust as against two parts and three nuts for the clamp. The other type is the Matthews boltless clamp, a malleable sleeve with tapered grooves, and a similarly grooved wedge-shaped key of easy taper which is driven home after the end has been threaded through the sleeve, around its attachment, and back again. It is claimed that it is much easier to install or adjust than other clamps, and that it has at least the capacity of the corresponding size. It certainly has fewer parts, and is said to be very satisfactory in service.

For the guy itself there are several grades of material which is almost universally known and spoken of as "strand," although strictly speaking it should be called stranded wire. To the electric railway men it is known by its diameter; to the electric light men by both diameter and breaking strength; and to the telephone and telegraph people the smaller sizes are known by their

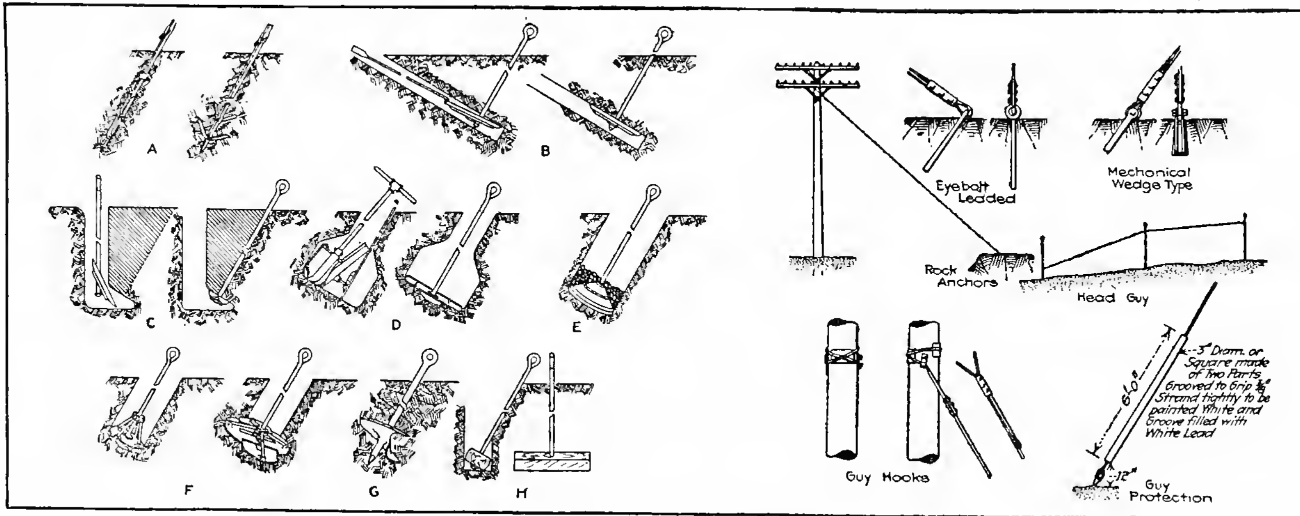


Fig. 29—Type of Guy Anchors

A, Harpoon Anchor; B, "Never-Creep" Anchor; C, "Hercules" Anchor; D, Miller Anchor; E, Bierce Anchor; F, "Ever-Stick" Anchor; G, Screw Anchor; H, Deadman Anchor (Deadman Ready for Filling of Hole). Drawings at Right Are Self-Explanatory.

breaking strengths, while the two larger sizes are rated at their breaking strengths when one strand has been cut. While this at first thought may seem peculiar, "there's a reason." The center wire is straight; the outside wires, because of their twist, are longer, and under strain they yield, throwing the load on the center one, thus tending to break it or to stretch it beyond the elastic limit of the material. By rating the "strand" at the strength of the remaining six wires this weakness is allowed for. The usual "strand" is generally known as "standard." Its strength is sufficient for ordinary work and it is soft enough to be made up by hand even in the half-inch size. Siemens-Martin strand has about 50 per cent more capacity; "high strength" is about twice as strong, and extra high strength about three times as strong as the same sizes in "standard." While this extra strength is very desirable in many cases, the material is very springy and stiff, and it is chiefly used for messengers, ground wires, long spans and similar purposes which do not require much bending, extra strength in guys when required being obtained by using two or more "standard" strands. Whatever grade is used it should always be "extra galvanized," because, due to its form, it tends to hold moisture and facilitates corrosion.

Strand can be had in practically any sizes between ⅛ in. and ¾ in. diameter, but the standard sizes and their strengths are as given in Table IV. As yet the "extra strength" has been standardized by no one.

A guy takes up a pull, usually at an angle to it, in which case the pole is the strut which resists the tendency of the two forces to come into a straight line. If we consider the first force to be horizontal, and applied at the same point on the pole as that to which the guy itself is attached, the pull on the guy, the thrust on the pole, and the force guyed bear the same relation to each other as do the sides of a triangle in which the angles are the same as those made by the forces. The distance from the foot of the pole to a point *at the same level* on the guy is called the "lead" of the guy; the distance vertically from the foot of the pole to the point of attachment of the guy is called the "height." If we let L stand for the lead, H for the height, and G for the length of guy between point of attachment to pole and the level of the foot of pole, if the pole itself is vertical G is the

TABLE IV—DIMENSIONS AND PROPERTIES OF STRANDED STEEL WIRE

Diameter	No.	Wires Size B.W.G.	Standard with	Known as	Strength in Pounds: Breaking "Standard"	Siemens-Martin	High Strength	Extra High Strength	Weight per 1000 lb. "Standard"
1/4 in.	7	14	A. E. R. A.	1/4 in. (with grade)	2,300	3,060	4,000	(7,600)	125 lb.
1/4 in.	7	14	N. E. L. A.	1/4 in. 2,300 lb.	2,300				
9/32 in.	7	13	A. T. & T. and W. U.	4,000 lb.	4,000			(10,900)	
5/16 in.	7	12	A. E. R. A.	5/16 in. (with grade)	3,800	4,860	6,000	(12,100)	210 lb.
5/16 in.	7	12	A. T. & T. and W. U.	6,000 lb.	6,000				
3/8 in.	7	11	A. E. R. A.	3/8 in. (with grade)	5,000				
3/8 in.	7	11	N. E. L. A.	3/8 in. 5,000 lb.	5,000	6,800	11,500	(17,250)	295 lb.
3/8 in.	7	11	A. T. & T. and W. U.	10,000 lb.	11,500				
7/16 in.	7	9	A. E. R. A.	7/16 in. (with grade)	6,500	9,000	18,000	(22,500)	415 lb.
7/16 in.	7	+9	A. T. & T. and W. U.	16,000 lb.	18,000				

hypothenuse of a right-angled triangle with L as the base and H as the height, so that:

$$G = \sqrt{L^2 + H^2}$$

and the ratio between G and L is:

$$\frac{\sqrt{L^2 + H^2}}{L} \quad or \quad \sqrt{1 + \frac{H_2}{L^2}}$$

Since the forces act in lines parallel to the sides of this triangle, the pull on the guy is in the same relation to the pulling force as the relation between G and L, that is

$$\text{Pull on guy} = \text{Horizontal force at attachment} \times \sqrt{1 + \frac{H^2}{L^2}}$$

For a raked pole, L must be decreased or increased, according as the pole rakes toward or from the anchor, by the distance from the foot of the pole to a perpendicular dropped from the point of guy attachment. If the pole leans so that this point is not in line with the anchor and the foot of the pole the value of L is

TABLE V—DIMENSIONS OF THIMBLES AND WASHERS

Thimbles For 1-in. Rod		Other Service	For Bolt or Rod	Outside or Side Round	Washers Dia. D Sq.	Thickness E Round U.S.Ga.	Thickness E Sq.	Dia. Round	Hole F Sq.
Ac	3⅝ in.	3 in.	⅜ in.	1 in.	....	14 in.	....	7/16 in.	....
Bd	15/16 in.	⅝ in.	½ in.	1⅜ in.	....	12 in.	....	9/16 in.	....
cm	⅜ in.	¼ in.	⅝ in.	1¾ in.	3 in.	10 in.	3/16 in.	11/16 in.	¾ in.
Dm	7/32 in.	¼ in.	¾ in.	2 in.	3 in.	9 in.	3/16 in.	13/16 in.	⅞ in.
Eb	9/32 in.	5/32 in.	⅞ in.	2¼ in.	....	8 in.	....	15/16 in.	....
Fl	1⅛ in.	¾ in.	1 in.	2½ in.	4 in.	8 in.	½ in.	1 1/16 in.	1⅜in.

the distance between the perpendicular and the guy at the level of the foot of the pole.

In practice it often happens that the force to be guyed is not applied at the same point as the guy or there may be several forces at different points; further, one or more may not be horizontal. In the first case if we multiply each force by the distance from the pole foot to where it pushes (or pulls) the pole, we get its moment at the ground. Adding the moments together and dividing by the distanee from the ground to the point of attachment of the guy gives the amount of force which at that point would have an equal moment; in other words the amount

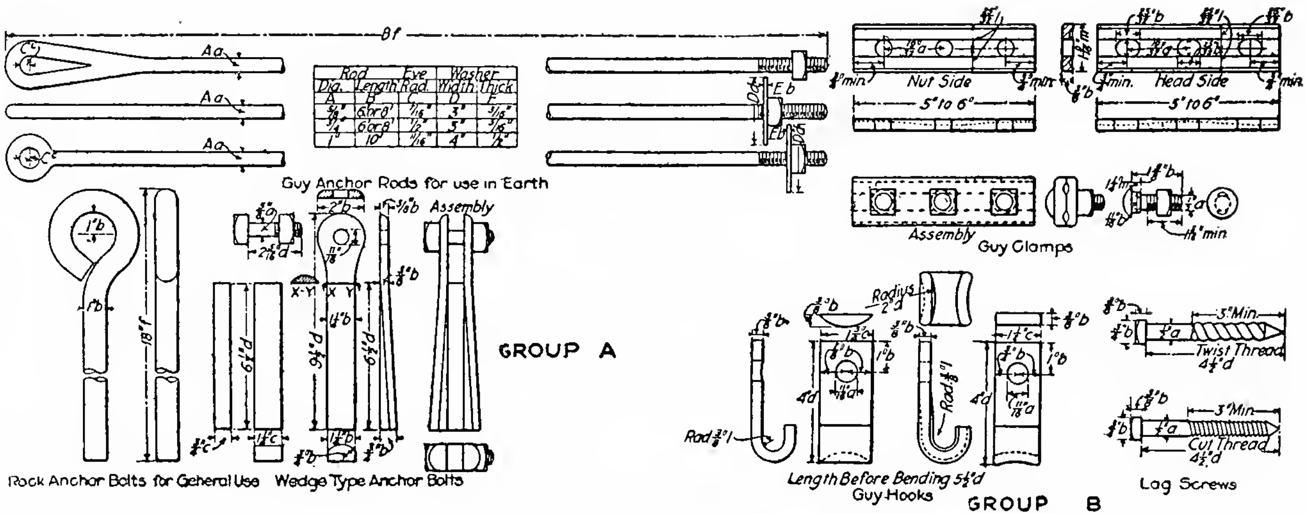


FIG. 30—FURTHER DETAILS OF GUY CONSTRUCTION (FROM ENGINEERING MANUAL)
Group A, Anchor Rods and Bolts; Group B, Guy Clamps, Hooks and Lag Screws

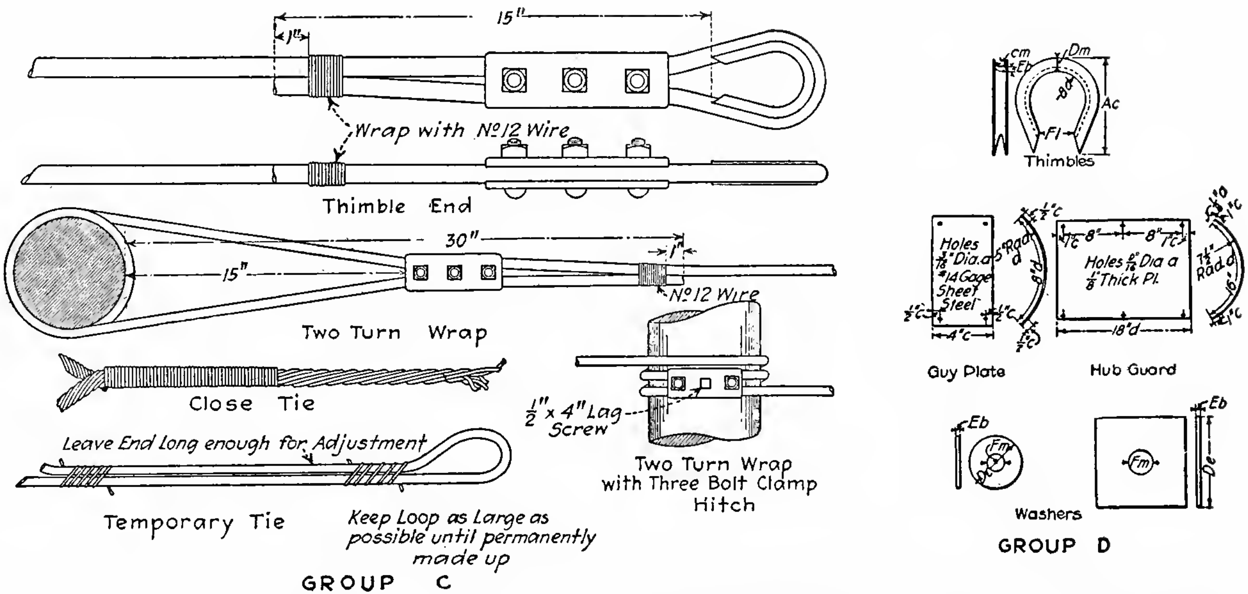


FIG. 30A—Group C, Details of Method of Making Span and Guy-Wire Attachments. Group D, Guy Plate, Hub Guard, Thimbles and Washers. (See Table of Dimensions on page 218.)

of the resultant of the forces. In case there are two or more guys with different points of attachment their resultant is similarly determined by taking the sum of their moments at the ground line and dividing by the distance from the ground line to the point at which it is desired to consider the resultant applied.

Splitting an Inclined Force into Vertical and Horizontal Components. If any force is not horizontal, the equivalent horizontal is readily found from the fact that any force can be separated into two or more forces operating in the same general direction, the relations to each other being the same as the relations of the sides of a triangle the angles of which are the same as those made by the original force with the two or more components. In our case the triangle is right angled. Knowing the inclination of the force, the ratio of the horizontal to the hypotenuse can be found, and by multiplying the inclined force by this ratio the horizontal component is found. All these and any similar problems are very readily worked out for an approximately accurate answer (and the answer can be had very accurately if the drawing is carefully done) by drawing a line the length of which as measured by some scale is equal to the amount of the force which is known, and by drawing from the ends of this line other lines making the same angles with the first that the lines of action of the forces they represent make with the line of action of the first. Their lengths measured on the same scale, are equal to the amounts of the forces they represent.

Clearly the more nearly a guy is in the direct line of the pull it is to resist, the more nearly will the strain upon it approach the amount of the force to be held. It is rarely practicable, except in the case of a guy parallel to the line, to make the lead greater than the height of the guy. The American Electric Railway Association specifications call for such equality if practicable, thus giving a guy stress which is 1.42 times ($\sqrt{1 + H^2/L^2} = \sqrt{1 + 1/1} = \sqrt{2} = 1.42$) the horizontal pull at the point of attachment. The Western Union permits on light lines a minimum lead of one-fifth the height (5.10 ratio) with a "required" lead of one-fourth (4.12), with one-third as the minimum (3.16), and three-fourths (1.67) "required" on the heavy fifty-one to eighty-wire trunk lines.

In the case of a light line the strain on the guy is rarely heavy

enough to cause it to slip, but with the heavier lines it is customary to protect the pole from any crushing tendency on the part of the guy by means of a guy plate, a sheet of No. 14 gage steel 8 in. long by 4 in. wide, which is nailed to the pole at the point of attachment of the guy. To insure that the latter stays on the plate, guy hooks are used on either side, being held in place preferably by a through bolt, although the use of lag screws for this purpose is common. The American Association calls for strain plates "behind guys the strain on which would otherwise cause material damage to wood poles" and for guy hooks where the lead is less than one-fourth the height, "or where as with guy plates the guy must be held in particular position."

Where Shall the Guy Be Attached to the Pole? The point at which a guy is attached to the pole should be as nearly at a point which would balance the forces against it as may be practicable; conditions of clearance. however, may compel attachment almost anywhere, but the method is standard. The strand is wrapped completely around the pole twice and the end is held by a three-bolt clamp about as far from the pole as the diameter of the latter when the guy is at right angles to the pole, the end being fastened as for the usual three-bolt hitch.

Where a line is on private way a guy is often fastened at the base of an adjacent pole, thus obviating the necessity for an anchor. If there is passage between the poles, however, the attachment, which in any case is by a two-turn wrap, must be at least 8 ft. above the ground, and the resultant pull on the pole serving as anchor makes this treatment usually undesirable.

The question of passing guys is often serious. On the company's own property they may be brought to earth close to a path and made prominent by a piece of board, a wood molding wired on, or a section of pipe slipped over the strand, this marker being then painted white. The pipe, which can be a piece of old boiler tube or other scrap, is best for a new guy, as in the case of an existing one the hitch must be opened. The wood forms are usually employed in such latter cases, and the portion in contact with the guy, and that portion of the guy itself, should be heavily white leaded to prevent corrosion. Where such treatment is not sufficient the guy is often carried to the top of a stub of sufficient height, on the opposite side of the way, and then led down to an anchor further outside. The stub should be set at least five ft. in the ground, and should have a

rake of about 4 in. to the foot; if the strain is heavy the guy is often attached to the top of the stub by a three-turn wrap, and two anchor guys carried from there to the ground, these last making angles of about 30 deg. with the line of the main guy. The stub is usually under heavy load, and for that reason should be a stocky stick, with top dimension not less than that of the pole it is used with.

Special Cases Have Often to Be Met. Where the clearway required is not more than 10 ft., and the guy strain is not too heavy, a strut may be set horizontally against the pole about its length below the point of attachment of the guy, and the latter led over its end and then vertically down to the anchorage. The pull on the latter is the same as for a "height" equal to the distance of the strut below the point of guy attachment, and a lead equal to the length of the strut itself. The latter acts as a column, and must have both the stiffness to prevent buckling and such protection at the end as will keep the guy from crushing into and splitting it.

It not infrequently happens that a guy cannot be placed against the pull to be resisted, but that room is available on the wrong side. In such case the situation is usually met by installing a "push brace," which is a pole which should be as heavy as the pole it is to reinforce and which is set with the same lead that would be given if it was a guy. The butt should go at least 3 ft. below the surface, and in any case below the depth to which frost is at all likely to penetrate. If the soil is very firm it may be set directly against the earth; but as a rule it is better to have it thrust against planking or a large rock to insure sufficient bearing to prevent any yield. If there is any likelihood of a pull coming on it, as is sometimes the case at an angle, where normally the stress is in one direction, but a heavy wind in the opposite direction may reverse it, a short section of pole or its equivalent should be bolted to the bottom. The upper end should be cut to fit snugly against the pole; whether the latter should also be notched is in question. The telegraph and telephone companies say "No," and it is obvious that a deep notch at this point would weaken the pole. It would seem, however, that a light notch, not heavier than a gain, would have little more weakening effect than the latter, and it certainly materially assists the through bolt, which is used so to tie brace and pole together that they will act as a single structure.

PART IV

CAR DESIGN

By Norman Litchfield, Mechanical Engineer

CHAPTER XXI

CLASSIFYING PASSENGER CARS FOR GIVEN CONDITIONS

THE business of transporting passengers successfully requires the co-ordination of many mechanical units, the development of any one of which forms a subject whose history would be of interest to trace. No single one of these can be said to be more vital to the operation of the railroad than another, but from the rider's standpoint it is the car, together with the character and conduct of the employees on the car, that determines his estimate of the road and its management. The power house may contain the most marvellously efficient generating machinery, the track may be of most modern construction, the thousand and one other details may be covered flawlessly, but if the car does not provide the means for transporting him to his destination in safety, comfort and speed, whether he be bent on business or pleasure, the passenger rightly criticises the management and if possible withdraws his patronage. In fact, it may be said for the average rider that the car and its crew typify the railroad.

The Car Is a Tool for Producing Mileage. In view of the above conditions operating officials and car designers have joined hands to produce types which their combined judgment and experience have shown to be necessary to meet the rider's needs. Within the last few years the increasing use of steel has made it possible to fulfill requirements which otherwise would have been unattainable and has served as an impetus in the design of many interesting types of car developed to meet different conditions.

The railway operator may be considered as the manager of a factory whose output is transportation, and the cars as machine tools for the production of mileage. The more mileage the car produces, the higher the efficiency of the investment in track, power station, etc., and of the car itself and the employees on the car.

The efficiency of the car itself, or its ability to produce mileage consistently and without attendant losses from damage claims, etc., depends upon the arrangement and construction of the car and its running gear, and also upon its motive equipment, brakes, and other auxiliary apparatus. The studies covered by these articles will, however, deal only with the design and construction of the car itself.

It is evident that the broad field of electric passenger transportation cannot be covered by one type of car. It is difficult to draw absolutely certain lines of demarcation, defining groups in which different types of cars should be used, but it may be said that these fall roughly into six main divisions into one of which any given set of conditions may be placed. Probably no phrase has been more misused than that of "local conditions," for while it may be possible to use a car 6 in. longer and 2 in. wider than some one else can, it does not necessarily follow that it is wisest to do so.

The six groups referred to follow:

1. Car for towns and cities up to 100,000 population.

2. The large car for the heavy industrial lines of cities in excess of 100,000 population.

3. The two-car city train, where the extreme condition of loading great factory crowds is met.

4. The subway-elevated car for multiple-unit train operation.

5. The car for light, frequent interurban service.

6. The car (motor and trailer) for long-distance high-speed interurban operation, large enough to include smoking, toilet, baggage and mail compartments.

It has been rightly said that any art goes through three broad stages, namely, invention, development and refinement. Electric railroading may be considered to have passed fairly well through the former two periods and to be, generally speaking, in the period of refinement. It is not that invention and development have ceased or will cease, but that they are no longer the outstanding feature of the art. The time was, and at a period not far distant, when the electric manufacturers designed an individual motor for every new set of conditions presented to them, even sometimes despite the wishes of the user. In fact, it is said of one official that he felt that the only safe specification for him to draw up was one reading, "I want a

motor the exact duplicate of those now operating on the A. B. & C. Railway." But that time is passing. The tendency is toward a smaller number of types of motors, each of which will cover a number of conditions. So it is fair to say that very nearly any set of conditions may be said to be included in one of the six groups enumerated.

Different Conditions to Be Satisfied According to Service. We may then ask ourselves, what do we demand of each class of car? In general, it may be said that in city surface cars there are four prime essentials, namely, capacity, facility for passenger interchange, ease of fare collection and freedom from boarding and alighting accidents.

These features are equally desirable for the town or city of less than 100,000 population and for the larger city, the difference being of degree rather than of essentials. It is axiomatic that the number of cars a road must operate on any given line depends first upon the total number of passengers at the peak period and secondly on the interval that must be maintained in order not to lose patrons. The second item is often controlling in the small town throughout the entire day, just as it is in the large city during the non-rush hours. In other words, a service giving a succession of small cars at frequent intervals is obviously more popular than one with large cars for which the patron has to wait, even though in neither case are the cars crowded. It therefore follows that the small cities have been turning more and more to the smaller car. But with the increase in frequency of the service comes an increased platform charge and power consumption per passenger carried or nickel received, and when it is remembered that the platform charge under the best of circumstances amounts to a third or more of the total operating expenses, it is evident that this feature is of great importance.

For the above reasons the one-man or so-called safety car has been developed. This type has been described in recent issues of the *Journal.* We have designated it for cities under 100,000 in population except on lines of unusually heavy travel. This at once provides the pre-payment fare-collection features, reduced weight and platform charges and reasonable facility of passenger interchange for the conditions under which it is supposed to operate.

Where the Biggest Car Is Needed. For the larger cities, the congested conditions require the use during the rush hour of as many cars as can be accommodated on the tracks, each of as great capacity as can be operated safely under the conditions of track curvature. In this case, therefore, the platform charge cannot be reduced by the elimination of the conductor. In fact, special aids must be provided to reduce the duties of the crew to the minimum. It therefore follows that fare collection and the quick loading and unloading of passengers become of prime importance.

Since the earliest days of electric railways considerable attention has been paid to the platform arrangement with the idea of facilitating the handling of passengers. In 1901 a long platform car was operated in Detroit with a railing dividing it into two passageways, the idea being that some passengers would always insist on riding on the platforms, and that by requiring them to keep behind a railing a passage could be kept clear. This naturally required an exceedingly long platform, and as city cars are limited in length, it subtracted that much from the desirable seating space in the body of the car.

The problem of easy passenger interchange is closely bound up with that of fare collection, the solution of which was first successfully made by Duncan McDonald and W. G. Ross in the first Montreal pay-as-you-enter cars in 1906. In a description of these cars Mr. McDonald pointed out that up to that time there were four systems of fare collection in vogue, namely, the register, the portable fare box, the receipt system, in which each passenger was given a receipt (the receipts being checked occasionally by inspectors) and the prize system, in which prizes were drawn for by the holders of receipt coupons. He concludes that the task imposed upon the conductor under any of these systems is well-nigh impossible of fulfillment, and that the only ideal system is that in vogue on the elevated and subway systems wherein passengers have to pay before entering the car on which they desire to travel.

While there have been many variants on Mr. McDonald's car, the essential soundness of his views has been amply demonstrated, and the fundamentals are embodied in every surface car now being built. This keeps the conductor close to the point where passengers embark and leave the car and has gone

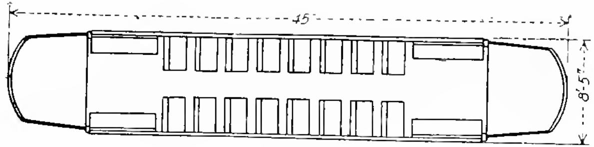


Fig. 1

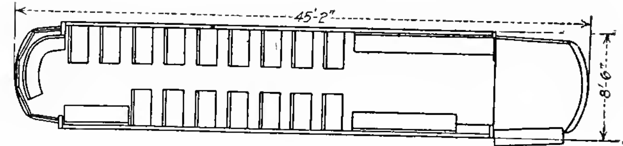


Fig. 2

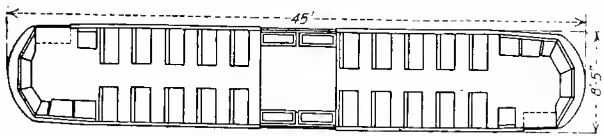


Fig. 3

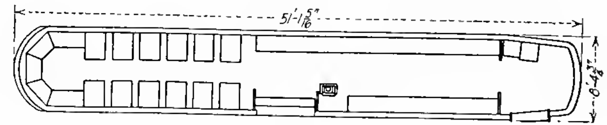


Fig. 4

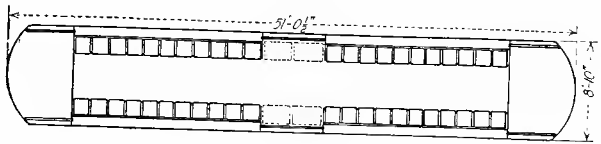


Fig. 5

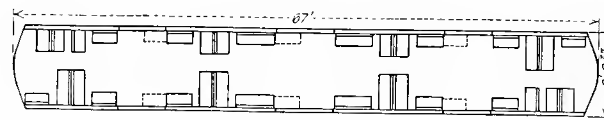


Fig. 6

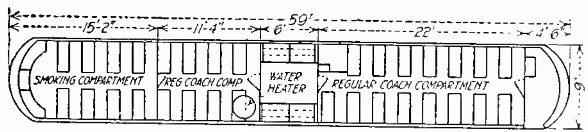


Fig. 7

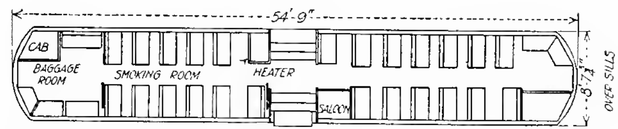


Fig. 8

FIG. 31—FLOOR PLANS OF CARS FOR VARIOUS CLASSES OF SERVICE

far in the reduction of that exceedingly troublesome and waste ful feature of old-time surface car operation—the boarding and alighting accident.

More latterly has come the use of platform doors and folding steps controlled by either the conductor or the motorman, and interlocked with the motors and control so that the car cannot be started until the doors are closed, and in some cases also arranged so that the doors cannot be opened until the car has come to a dead stop. These features have to a large extent eliminated the boarding and alighting accident.

The final factor in facilitating passenger movement has been the elimination of steps by careful design, dropping the car floor to a minimum distance above the street level. All of these factors have brought the remarkable results of handling passengers at the rate of about one second each, reducing the lost fares to a fraction of 1 per cent, and the practical elimination of boarding and alighting accidents. There are to-day four distinct types of large city cars, as follows:

Rear-entrance, front-exit, or ordinary pay-as-you-enter car, Fig. 1, page 231.

Front-entrance, front-exit, or near-side car, Fig. 2.

Center-entrance, center-exit, Fig. 3.

End-entrance, center-exit, or "pay-as-you-pass car," Fig. 4.

Each of these types has its advocates, and all possess certain distinctive features, but nevertheless have in common the fundamentals which have already been outlined.

We have already pointed out that in large cities it is necessary during the rush hours to run as many units as is physically possible, each of which must be of maximum capacity. A practical limit in the size of the car is finally reached at a length of from 45 ft. to 48 ft. When a larger unit is demanded for use under conditions such as the home-going of the employees of one of our large industrial plants, all at the same hour, it becomes necessary to employ the two-car train. This is sometimes composed of a motor car with a trailer, but this combination has a number of disadvantages; and the development of a light, inexpensive type of multiple-unit control and semi-automatic air brake has made possible and economical the use of two motor cars. The latter arrangement is rapidly coming into favor. The remaining feature to be thoroughly developed is that of the

automatic electric coupler, and it is reasonable to expect that this will be accomplished in the near future.

Door Location Vital in Subway Cars. In city cars operated in subways fare collection disappears, but passenger interchange increases in importance, and there is added the feature of protection against damage from collision. For the interchange of passengers it has been found desirable to make the proportion of doorways to passengers carried as large as possible and to minimize the distance of any passenger from a door. The size of car is largely controlled by existing conditions of track curvature, length of station platform, and by the determination of the most economical unit for combining with trains of different lengths at various hours of the day when the density of traffic varies. Two examples of this type are shown in Figs. 5 and 6.

In interurban cars the comfort of the passengers becomes a controlling factor, requiring the introduction of features not demanded or even desired by the public in the other class of car. (See Figs. 7 and 8.)

City Cars Need Not Be Weighted to Be Collision Proof. It may be noted that the feature of protection against collision begins to enter with the high-speed car. By this it is not meant that reasonable precautions against damage from collision should be overlooked in the city car but that city cars do not need to have weight put into them to make them, as it were, collision proof. The speed at which they operate is so low as to make them ordinarily controllable with the modern brakes. There is no need to prepare them for blows unattainable except at speeds they will never be called upon to reach. A close analogy may be found in the Ford automobile, which, admittedly not designed to withstand collision, wends its way through the most dense traffic in safety due to its ease of control. Mr. Ford himself has pointed this out in his recent criticism of certain steam car weights, that it was like using a 75-lb. basket to carry 25 lb. of groceries.

From 1250 Lb. to 500 Lb. per Seat. Considerable advance has been made in recent years along these lines, as may be evidenced by the instance of a city surface car built some years ago weighing approximately 50,000 lb. and seating forty passengers, making a dead weight of 1250 lb. per seated passenger; whereas cars now available for similar service weigh 35,000 lb. and seat

fifty passengers, or 700 lb. per passenger. In fact, smaller cars are in use whose dead weight is not over 500 lb. per seated passenger. These reductions are due partly to the improvement in materials and design of motive apparatus forming a part of the car equipment; and partly to the use of steel in the car and truck construction disposed along scientific lines at the points where it is needed. The methods by which the proper proportioning of various parts may be arrived at will be reviewed in a later article.

CHAPTER XXII

SAVINGS ATTAINABLE WITH PRESENT-DAY CAR DESIGN

In his previous article introducing the subject of car studies the writer pointed out that a car is essentially a machine tool for the production of mileage. In any study of economies that can be effected in the operation of cars on an electric railway, therefore, there are three distinct general lines along which to pursue the possibilities, the first being an increase in production of mileage through reduction of the idle hours, the second an increased efficiency in the rate of production, and the third an improved quality of the product. It is readily seen that it is impossible to obtain results along these lines without co-operation of both the transportation officials and those responsible for the care of the cars, although in the first line, namely that of production, the transportation engineer stands more alone.

Getting More Revenue Miles from a Given Car. By the increase in production is meant the additional profitable mileage that can be produced with a given number of cars, by stimulation of travel through pleasure riding, special excursions, etc., or by other agencies which will permit the company's rolling stock to be used a greater number of hours per day than is now the case. On the average property this probably does not now exceed eight or ten hours.

This low figure, of course, is due to the fact that during the hours when people are going to and from their work there may be as many as sixty per cent more cars required than are needed during the remainder of the day, the latter number being determined largely by the interval necessary to be maintained between cars in order not to lose business. That is to say, during the middle of the day a prospective passenger will walk a reasonable distance rather than wait an undue time, or if the distance be too long to walk comfortably, he will complain either to his

neighbors or to some regulating body, and if possible, withdraw his patronage altogether.

On the other hand, during the rush hour, the problem is chiefly that of transporting a maximum of passengers in a minimum of time, which often requires as many cars as can physically be operated over the tracks. This large number of cars, of course, is greatly in excess of the number required to maintain a reasonable interval in the middle of the day, and hence all operators have bent their efforts toward an increased use of these excess cars during the off hours.

By the efficiency in the rate of production is meant the increase in active mileage per car without the actual creation of new business, and the reduction of idle mileage. This phase of the subject has rather more angles to it than that of increasing the amount of production, being more affected by details. Among the chief possibilities are the following:

The reduction of the idle or non-revenue-producing mileage through storage facilities at both ends of the line, and the short-routing of cars by a careful study of the origination and destination of travel.

The increase of schedule speed through adoption of skip stops, higher rates of acceleration and braking, quick interchange of passengers in loading and unloading through improvements in car design and fare collection facilities.

The reduction of platform charges through the use of one-man cars, two-car train operation, or double-deck cars.

The reduction of accident claims by providing conveniences for the motorman in the handling of his car, thus helping to prevent front-end accidents, and by improving the interchange arrangements so as to eliminate the boarding and alighting accident.

Last, but not least, the provision of all facilities possible to enable the large majority of honest conductors to obtain all the fares, and to restrain the small minority of dishonest employees from purloining fares. In this branch of the subject come also the use of devices to stimulate an increase in coasting, and of other devices and methods of saving power.

By the quality of the product is to be understood those features which tend to make the passenger satisfied, such as good lighting, heating, ventilation, and riding qualities, and freedom

from delay or the discomfort and exasperation induced by the request to "take the next car," due to failure of the car equipment.

As these studies have to do only with cars, we shall not dwell further on the subjects of short-routing and car storage other than to call attention in passing to the fact that an increased length of car means a larger house, and a heavier car, a stronger and more expensive building construction.

When we pass to the question of the increase in schedule speed, however, we find that the car itself becomes a vital factor in many ways. Much attention has recently been given to the so-called skip-stop system, and special stress has been laid on the increased schedule speed and the saving in power through the reduction in the number of stops and starts. It is evident that if the number of stops is reduced more people must be handled per stop and consequently platform and fare collection arrangements must be adopted to take care of the increased number of passengers without congestion.

But in addition to this feature there enters one which has not received so much consideration, namely, the fact that in low-speed operation such as city service, the cost of car maintenance is very largely affected by the number of stops per mile.

The cost of maintenance of car equipment on a well-managed road will run from 2 to 2½ cents per car-mile. Taking an average of say eight stops per mile this would amount to a maintenance cost of about ¼ cent per stop. It cannot be claimed, of course, that the cost of maintenance increases or decreases in exact proportion to the number of stops, but on the other hand it is quite clear that if a car needed to make but one start during its whole trip, the wear and tear on the equipment would be tremendously less than under the actual conditions, where many stops per mile have to be made. Trolley poles, controllers, motors, doors, brakes, wheels and so on *ad infinitum* would bear eloquent testimony to the difference in operating conditions.

No car equipment man needs to have pointed out to him the difference in life of the same type of brakeshoe on different lines having unequal numbers of stops per mile and the humble brakeshoe may well serve as a measure of the severity of the service. Thus it is certain that the skip-stop has a marked effect on the cost of car equipment maintenance.

Proper Stepping of Resistors Permits High Rate of Acceleration. The possibilities through increased rates of acceleration and braking, use of proper gear ratio, and coasting devices, all have their influence on the schedule and the cost of power. They have received so much attention, however, that it seems unnecessary to dwell upon them here, further than to point out that a high average rate of acceleration can be maintained without danger of slipping the wheels and without discomfort to the passengers, provided the individual resistance steps are properly proportioned so as not to deliver a violent blow either to the passengers or to the wheels.

It must be borne in mind that any shock is the result of two things—the moving mass and the instantaneous rate of acceleration. This is to say, with an average rate or acceleration as low as 1 m.p.h.p.s. and an improperly graduated resistance, excessive instantaneous or momentary rates of acceleration are encountered—(possibly as high as 10 m.p.h.p.s.), which are exceedingly uncomfortable and which slip the wheels. On the other hand, if the resistance is properly graduated and the controller is skillfully manipulated a steady rate of 2 m.p.h.p.s. or even more can be maintained without difficulty. Similarly the rate of braking can be increased, either by an increase in the cylinder pressure or some slight change in the brake rigging so that the maximum force on the brakeshoes can be exerted which experience has shown to be desirable.

Making It Easy for Passengers to Board, Alight and Pay Fares. No phase of car design has perhaps received greater attention in the last few years than that of passenger interchange and fare collection, resulting in the development of a number of very interesting types of cars, and consequently in the formulation of certain fixed fundamentals. Among these are the carrying of the floor as close as possible to the ground, the reduction or elimination of steps, the provision of convenient means for operating doors, the use of fare boxes, and safety interlocks between doors and car control. All of these features contribute to the ease of operation of the car, increasing its schedule speed and reducing accidents. They are therefore classed as economies.

The one-man car, the double-deck car, and the two-car city train are in the same category in regard to economies to the ex-

tent that all are designed to provide transportation facilities of character equally as good as the more nearly standard types of car, and at a reduced platform cost. It would seem that the small one-man car of very light weight should prove increasingly popular in many classes of service, just as the two-car train is doing in others. While the double-deck car has not come into general use, it is probable that its capabilities and possibilities have not as yet been fully exhausted.

Passenger Comfort Features Can Be Improved at a Saving. When we come to consider the quality of the product which the car, considered as a tool, turns out, such comfort features as lighting, ventilation, heating, riding qualities, etc., would seem to be in the nature of luxuries, rather than economies. But inasmuch as they all form features of present-day car equipment that cannot be dispensed with, a little consideration will show that quite considerable economies can be effected by proper design and maintenance.

Take, for instance, the matter of lighting. The successful development of the tungsten lamp soon led to its general adoption for car lighting, and now the practical discontinuance of the manufacture of carbon lamps makes the use of the tungsten lamp imperative. It becomes important, therefore, to select very carefully the characteristics of the lamp which is to be used. The old carbon lamp in general use was of 16 c.p., consuming about 60 watts. Where voltage conditions were reasonably good this was generally considered to provide adequate lighting.

In changing to the tungsten lamp, consideration should be given to the points on the line where low voltage occurs and to the importance of maintaining adequate lighting at these points. A question also is the amount of light which it is necessary or desirable to provide. For instance, it is generally agreed that from 1½ to 2 foot-candles at a plane of 36 in. from the floor give adequate illumination, but if very wide fluctuations of voltage occur, and the lighting is designed to give 1½ foot-candles at the lowest point, then at the high-voltage points a very much greater degree of illumination is obtained. As the life of the tungsten lamp falls off very rapidly with increases in voltage, it is important that a lamp of proper characteristics be selected, so that a reasonable life will be obtained.

The photometric determination of illumination in a car is very simply made, and a check-up of this kind will often point the way to considerable operating economies. A step further, and one which in many cases is desirable, is to purchase the lamps to a specification requiring certain tests to be made in the presence of an inspector. Study of the operating and manufacturing conditions will finally dictate the selection of a lamp which will have the most desirable balance of life, power consumption and illumination.

A further point is that considerable increase in illumination can be obtained by a change in the color of the ceiling. These points, it is to be noted, are exclusive of any change in the arrangement of the lamps or of addition of reflectors, all of which may involve alterations to an extent not always justified.

With regard to heaters the most obvious possibility of economy is in some method of operation whereby no more than sufficient heat will be provided. Much can be done by proper co-operation with the transportation officials in the issuance of orders for the use of the heaters and the control of the doors, especially in cars having end doors. A simple test of heating any car to a given point, then turning off the heat and recording the temperature, say, every minute, with the car standing still, and then repeating the test with the car in actual service, will prove very instructive. It will show how much heat is lost through opening doors, ventilation, etc.

Thermostatic regulators are also now receiving some attention, but inasmuch as they require an extra investment and add a hazard or element of failure and possible complaint, it is well to make a careful study of the actual total amount of heat used for power in an average year, and the actual amount of excess heat that is supplied by the existing graduations of heat control by the ordinary switches. These data, together with the cost of power (coal and water only if the company manufactures its own power), will give an indication as to whether regulators will prove desirable or not.

The conclusion will be influenced by the relation between the total numbers of cars owned and of car-hours operated. That is, sufficient regulators must be purchased to equip all cars, whereas only a certain proportion of these cars will be used

enough hours each day to make the current saving profitable. The matter is also further influenced by the character of the climate, frequency of stops, kind of service, etc., so that it is essentially one in which the existing local conditions must be carefully studied. In studying this question it should be understood that the difference between the power used in winter and that used in summer does not necessarily represent the heater load, as in winter season more passengers are often carried, more stops are made per mile, vehicular congestion is greater, etc., these items sometimes in themselves causing a large increase of energy used per car-mile.

Heavy Trucks Not Essential to Easy Riding. Good riding qualities in a car are naturally desirable and are often thought to be obtainable only at the expense of excessive weight. It is very questionable whether even very high speeds require weight, in itself, to produce ease of riding, and it is certain that ordinary speeds, say up to 45 m.p.h., do not. The essentials are chiefly a proper side-swing motion adequately damped against excessive lurching, sufficient side-bearing and pedestal clearance, and correctly designed springs. Inasmuch as the cost of each additional pound has been estimated by various authorities to amount to as much as 5 cents per pound per year, it is evident that it is exceedingly wasteful to apply weight to a car simply with a view to improving its riding qualities, when this result can be accomplished otherwise. Instances have been met where it was possible by careful redesign to eliminate as much as 8000 lb. per car. For each lot of 100 cars this would amount therefore to $40,000 per year, a very substantial saving.

In the elimination or reduction of run-ins caused by car equipment failures we strike a mine whose depths cannot be plumbed in the limits of such an article as this. There are, however, certain outstanding features to which attention may be called, the chief of which is the constant recording and analyzing of recurrent failures.

From the analysis comes the knowledge making possible the redesign of the offending part, or the formulation or adoption of a specification or practice which will prevent the repetition of the failure. The word "specification" should be taken in its broadest sense, not necessarily a detailed statement, but possibly

simply the adoption of some one make of article which has proved satisfactory. The chief thing is not to keep on replacing the very thing which has proved a failure.

Instances of the above will immediately suggest themselves to all familiar with car equipment, one of the most striking being that of gearing, where improvements in materials and their proper selection for the service have resulted in an increase in life from a former figure of 50,000 miles to one of more than 200,000 miles.

Each Road Needs at Least One Defect Analyst. Two questions naturally arise for the average road, one being how to make use of the scientific knowledge available from different sources, the other how much use should be made of specifications and inspection services. Should each road have its own force, however small, for the scientific analysis of problems, should it go for information to other and larger roads, or is it desirable to employ outside consulting engineers? Similarly, should the road attempt to inspect its own materials, or employ the services of inspection bureaus? This is a problem which can, of course, be settled only by each individual management. Roughly speaking, it may be said that in each organization the attempt should be made to include at least one man whose duty shall be to attend to the recording and analysis of failures and to keep in touch with those roads and engineering associations which are developing or recording methods and materials which have proved satisfactory.

As to detailed specifications, their uses are twofold: first, to insure obtaining the material desired, and second, to yield the advantages of competition which could not be made use of if but one definite make of material were named to the exclusion of all others.

In connection with both of these points, however, two things must be borne in mind. The first and more important of these is that if the user does not understand the specification it will often be wiser for him not to use it at all but depend rather on the word and experience of some reputable manufacturer. It is self-evident that no specification, however carefully drawn, can supply a lack of experience or integrity on the part of the manufacturer. There are extant a number of specifications which are a "hodge podge" of extracts from various originals

combined by inexpert hands into a heterogeneous mass. The various provisions of these are absolutely contradictory, and hence make them the laughing stock of reputable manufacturers and tend to make the latter "gun-shy" of any specification not prepared by themselves. Faulty specifications, and their incorrect use, therefore, do not tend to economy.

The second point has to do with inspection of materials. Here an attempt should be made to analyze requirements so as to determine fully just what materials are most vital to have properly inspected and tested, and what others can be purchased from ordinary merchantable stock, for the tendency in inspection, as in many other things, is to degenerate into red tape. Such inspection as can conveniently be made by the company's own employes should be so handled, and the balance should be turned over to reliable inspection bureaus.

Don't Hesitate to Conduct Tests and Inspections. Conditions vary considerably with the size of the property and its local situation, but the following would seem to be a reasonable procedure in connection with miscellaneous materials. Taking first the materials themselves, the chief supplies used for car equipment are gray iron and malleable iron castings, bar iron, steel shapes and plates, steel castings, copper cable, insulating materials, brass castings, bar copper and lumber.

Cast iron, being generally used in places where there is little tensile or bending stress, will usually be found satisfactory provided it is of good, soft, gray quality. This is easily ascertained by fracture. So with malleable iron, which is used in places where some degree of flexibility is necessary, the quality of the product can generally be determined by bending. When it comes to bar iron and steel, we enter the region wherein it may be well to resort to more elaborate tests. But here again the engineer need not sacrifice his judgment to the fetish that "everything must be tested."

If the material is for a piece the failure of which does not affect safety, and little trouble has been experienced with the part, ordinary stock material may be used at less cost than if rigid specification were required.

To insure reasonably good open-hearth steel, two simple tests can be made. In one the piece is bent cold around a 1-in. radius, and in the other a chemical determination of the per-

centage of phosphorus which it contains is made. The phosphorous content should not exceed 0.07 per cent. As the importance of the piece grows the specifications may be made more complete until the full tests required in the standard specifications are made. The above often holds also for steel castings, as in many cases a piece has only to withstand stresses which are but slightly in excess of these which could be met by the use of cast iron.

The copper parts and insulating materials are very generally put to use where safety and durability are prime features and hence should receive the maximum degree of care in selection that the user feels justified in applying. As the manufacturers are fitted to make the necessary tests at their own plants it is comparatively simple to have an inspector witness these tests.

The requirements for lumber on the average car are not severe enough to necessitate elaborate tests, simple inspection being usually sufficient. Completely fabricated parts of special nature such as gearing, brushes, lamps, brakeshoes, buses, etc., can be effectively checked up as to their relative cost and efficiency by simple tests in the shops, and by recording the life and the mileage, at a cost the sum total of which is insignificant compared with the possible economy.

In all these matters it should be borne in mind that there are "acid tests" of the desirability of any specification or requirement. Will it make the article (1) safe, (2) more durable, (3) cheaper? The purchaser must be convinced that every requirement of the specification tends to one or more of these ends, and if he cannot be so convinced, it is often better to omit the requirement.

CHAPTER XXIII

CAR BODIES MUST BE DESIGNED FOR ECONOMY AS WELL AS STRENGTH

In a previous article the writer gave a general classification of electric railway cars into several distinctive types, varying more or less in construction to meet the varying conditions of service for which they are designed. The differences noted therein had to do with arrangement rather than with principles of construction. All of the types contain essential elements in common, whether the service be, on the one hand, of the extreme light-weight, one-man character, or on the other, the heaviest train operation.

These essential and common elements may be enumerated as follows: (1) Safety and comfort of passengers. (2) Ability to carry the load and withstand reasonable shocks. (3) Durability. (4) Ease of manufacture and repair. (5) Minimum weight.

The primary feature from a structural standpoint is the ability to carry the load and to withstand end shocks. The relative importance of the two subdivisions of load and end shocks will depend largely on the character of service, as each different class of service contains one or more controlling elements which either may be absent entirely in the others or may be of less consequence. Variation in the design may thus be permitted, not so much in the fundamental principles as in the degree of intensity which one feature bears to the whole.

In Steam Freight Cars Buffing Strains Predominate. A good instance of this is a freight car in steam trunk-line service, in which case cars are operated in long trains, pulled or pushed by a locomotive at the extreme end, or dropped down the grade of a "hog back" freight yard against a bumping post. All of these are conditions combining to produce enormous buffing strains, which thus become the controlling features. The importance of this feature is well recognized and its effect

is summed up in the 1915 report of the M. C. B. committee on car construction which contains the following:

> During the past year the committee has given careful consideration to the various types of existing freight-car designs, and has investigated current troubles and analyzed causes for such troubles. A large number of failures can be traced directly to weak center-sill construction and to incorrect analysis of draft-gear effect on center-sill construction.

The committee then proceeds to the consideration of the intensity of the end force which should be allowed for, and concludes that this should be assumed equivalent to a static load or steady pressure of 250,000 lb. Some idea of the relation that this load bears to ordinary electric car service can be obtained by considering that a typical double-truck city surface car with passenger load will weigh at least 50,000 lb., and that a force of 250,000 lb. would be about sufficient to slide the wheels of a train of twenty such cars coupled together.

Just as we have the standard freight car at one end of the scale, so at the other is the ultra light-weight car for city service, wherein the operating speeds are so low as to make the end forces practically negligible as a factor in the car construction.

A somewhat parallel case in its effect on design is that of passenger interchange, or facility in loading and unloading on a pay-as-you-enter surface car where it is of prime importance to have ample platform capacity to permit the picking up of a large number of passengers. Of only secondary importance is the necessity for making the steps as low as possible. These features introduce a condition of an overhung weight which must be borne on dropped platform sills. They are points which do not have to be given as much weight in the design of a car to operate in service where the station platforms are level with the car and platform floor, thus permitting the use of a continuous straight sill.

Passenger Interchange Needs Dictate Features of Car Design. Detail differences and distinction could be multiplied and cited at length, but these soon become evident to the designer as he studies his own problem, and consideration of the structure of any fairly representative car will focus attention on the chief essentials. For this purpose a short analysis is

given in the present article of a level-floor car body weighing with equipment approximately 40,000 lb., and designed to carry a maximum load of 160 passengers weighing 140 lb. each.

The car body can be considered simply as a load-carrying structure or bridge, the abutments or points of support being the center plates of the trucks. It is customary to provide clearance between the body and the truck side bearings, to allow the body to rock slightly to improve riding qualities and to give ease in rounding curves, so that the side bearings cannot be considered as points of support. Cross members or bolsters are provided to carry the load of the sides and the roof to the center plates. These are designed as cantilevers resting on the center plates. The detail design of these bolsters will be discussed later, attention being given first to the longitudinal structure of the car, in relation to its function of carrying the load from bolster to bolster. There are various types of floor frames, but in general they consist of the following main members: Two side sills, two center sills, two end sills, two bolsters and two main cross-bearers. The choice as to whether the load shall be carried equally by all longitudinal sills, by the center sills alone, or by the side sills alone has been influenced in the past by the conditions of service, the nature of the materials used in the car construction and the methods of manufacture. Thus early types of freight cars had truss rods under each sill, so that each would carry its portion of the load, and cross members or "needle beams" were provided underneath the longitudinal members to distribute the load more or less evenly among them all. As the length of freight trains increased, the buffing shocks became excessive. As pointed out in the foregoing, they soon became a controlling feature, and forced the use of powerfully constructed center sills and, as it were, automatically the center sills became the chief load-carrying members. This followed because they had necessarily to be built strong enough to resist the end strains, and the structure thus formed was available for carrying the vertical loads. The same feature has had its influence in the construction of passenger cars for high-speed trunk-line service in long trains, many of which are constructed with heavy center sills. In these the side sills are comparatively light and supported from the center sills at a number of points by cantilever arms.

But on cars for electric service the center sills have not been very generally used for load-carrying purposes and for two reasons. One is that the attaching of the electric and air-brake apparatus to the bottom of the car makes it undesirable, from the standpoints of both installation and inspection, to have a deep center sill. The other is that the conditions on the usual electric road are not such as to be likely to impose any excessive end strains. Furthermore, the sides of the car have in any event to be built sufficiently deep to provide standing height and the necessary air space for passengers and hence, as the sides are there for these purposes, they are also economically available for use as load-bearing members. The center sills are, therefore, as a general rule made comparatively light, and while they carry a portion of the passenger and car equipment load directly to the bolsters, they cannot support the entire load of themselves. They are, therefore, reinforced or propped up by two cross-bearers which carry the excess load to the side frames.

The side frames thus get a combined load consisting of their own weight, that of the roof, a fairly uniformly distributed load of that portion of the passengers, floor and apparatus directly supported by the side sills, two concentrated loads at the cross-bearers, and an overhung load outside the bolsters.

To meet these conditions various forms of side construction have been devised, and those in general use may be divided into three main classes: (1) Truss rod, (2) plate girder, and (3) framed truss. The origin of the first of these, the truss rod, dates back to the early simple roof and bridge trusses wherein, when the distance to be spanned became too great for a simple beam, resort was had to a truss rod and queen post to prop up the beam at the center. This plan naturally was adopted for the same reason in car construction, but it was soon found to be inadequate in itself, as it provided no stiffness to resist the oscillations set up by the motion of the car along the track. Consequently it became the practice to use deep planks set on edge on the tops of the side sills, and bolted thereto, these being known as truss planks. These also were found insufficient, and stiffening trusses were added. These consisted of wooden struts carefully fitted between the sill and the belt rails, and tied together with iron rods put into initial tension with turnbuckles. These trusses were also used to help support the overhung plat-

form loads. As these trusses were at best very flexible the truss-rod lent itself admirably for use with them, but with the advent of steel in car construction the truss-rod became unnecessary. The side frame in itself is now sufficiently strong and rigid to carry the load without further reinforcement.

The earliest form of steel-side construction was that in which the load was carried on a structure at or below the floor level. It consisted either of a pressed or built-up beam, deepened at the center and from its shape generally known as a "fish-belly" girder. This was eminently well adapted to a car in which, as at first, only the underframe was of steel, the sheathing, posts and roof being as yet of wood.

With the further use of steel for side posts and sheathing, it was at once evident that for comparatively light service, with small buffing strains, the "fish-belly" side construction was superfluous. The belt rail, side sill and sheathing in themselves formed a plate girder simple in construction and sufficiently strong and stiff for a car having no doors in the sides between bolsters. This permitted the use of light side posts and roof construction, and gave a very satisfactory structure.

When the congested traffic conditions in the larger cities began to force the use of additional doors in the sides of rapid transit cars in order to provide quick passenger interchange, some other method than the side plate-girder had to be used as the doors cut the girder in half. The designer thus found himself confronted by three alternatives: First, to resort to the old "sub-fish-belly" girder; second, to patch the two halves of the side plate girder together, either by a stiff frame carrying the compression strains over the top of the doorway or by a short "fish-belly" girder under the door, and third, to treat the entire side of the car as a truss.

The different types of girder construction are shown in Fig. 32. When we come to consider the use of the entire side structure of the car for carrying the load, it must be remembered that the car side is more than a simple load-carrying structure such as a bridge truss, in that it is also the side wall of an inclosed moving vehicle designed primarily for the comfortable housing of passengers. As such, certain parts must be included regardless of whether the supporting structure is a truss rod, a girder or a truss. These are the floor sill, the window sill, the

top member generally known as the side plate, the sheathing, the posts, and the windows. The desirable proportion of the windows from the standpoint of the comfort of the passengers precludes the use of diagonals, which form a necessary part of a true truss. In such a truss all of the members are either in straight tension or compression without being subject to bending. The place of these diagonals therefore has to be taken by the posts which are put under bending stress, resisted and braced either by the belt rail and sheathing directly or by an independent structure below the window sill and back of the sheathing.

Some Departure From "Orthodox" Bridge Design Is Necessary. To the designer of bridge and roof trusses, the bending of main members is considered "anathema" and not to

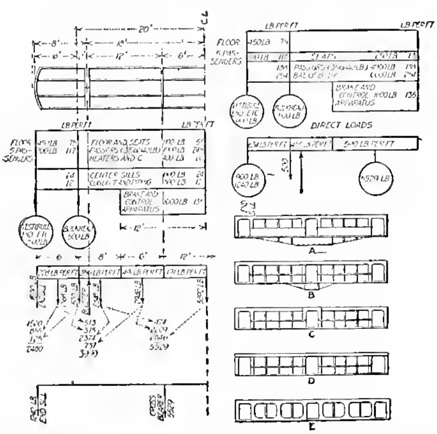


FIG. 32—AT LEFT, LOADS ON CENTER SILLS AND LOADS TRANSMITTED TO SIDE SILLS. AT RIGHT, ABOVE, DIRECT AND TRANSMITTED LOADS ON SIDE SILLS. AT RIGHT, BELOW, DIFFERENT TYPES OF GIRDER CONSTRUCTION.

be tolerated. But as before stated the side of a car is not a structure alone, and inasmuch as the strains in the posts can be quite definitely determined and sufficient resistance against bending provided in normal dimensions of posts of not excessive weight, it has proved entirely satisfactory in electric car design to follow this procedure, the structure being as shown in Fig. 32-D.

To overcome the bending stresses herein mentioned, and to produce a side structure which should be as nearly as possible

a true truss, the design shown in Fig. 32-E has been used somewhat. In this the windows are rounded, giving the effect of a somewhat modified Howe truss, and the design has proved entirely satisfactory.

Generally speaking, the use of the car side for carrying the load in one form or another has reached the point where it may be considered as a fixed element of all electric car construction for other than trunk-line purposes.

Good Engineering Requires Elimination of Unnecessary Weight. The railways have for a number of years felt the desirability of obtaining all possible economies in the use of power,

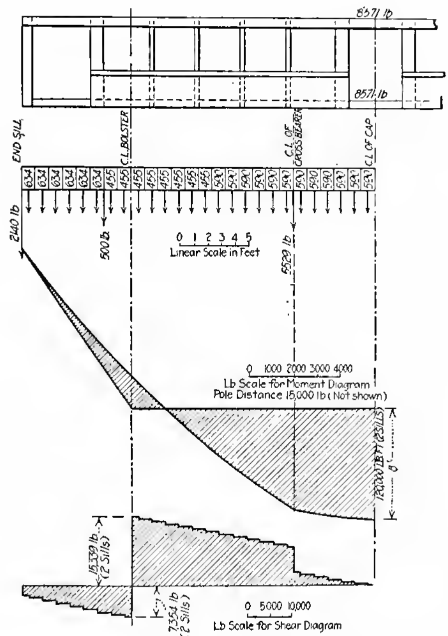


Fig. 33—Loading, Moment and Shear Diagrams of Side Sills

and have recognized the expense caused by excessively heavy cars. Each item entering into the construction of the car and its equipment has received careful attention as to the possibilities of reducing weight. To this end it is necessary to ascertain as nearly as possible to what stresses each part of the construction is subjected, and then to design the part specifically

to meet those stresses, a course which the use of steel has made possible without involving excessive weight.

For the floor framing the stresses imposed by the vertical loads may be approximately determined by the use of loading diagram such as shown in Fig. 32, in which approximate estimates are used of the weight of component parts of the car structure together with such data as may be available in regard to the operating apparatus which is carried on the car body.

With the loading diagram of the floor framing thus plotted, the individual loads on the side sills are laid off to some convenient scale as in Fig. 33, the force and equilibrium polygons are drawn, and the resulting moment and shear diagrams are constructed. In the figure as reproduced the force polygon and rays have been omitted for convenience. The method of the force and equilibrium polygons is one of the simplest for determining the bending moments. It is described in detail in several standard works on analytical mechanics, and need not, therefore, be explained here. It will be seen that the maximum bending moment is at the center of the car, and amounts in the case under consideration to 120,000 lb. ft. The distance between the neutral axes of the top and bottom members of the side frame or the so-called ''effective depth'' being approximately 7 ft., the stress in these members is 8571 lb.

Having determined this stress the next question is that of the safe allowable unit stress. This, of course, is a matter which is influenced by such points as operating speeds and track conditions. It is also one which for the electric railways has not been authoritatively standardized, and has been left more or less to the individual judgment of the designer.

For trunk-line service an authoritative specification is that of the United States Postoffice Department for the construction of steel postal cars as follows:

All parts of the car framing shall be so proportioned that the sum of the maximum unit stresses shall not exceed the following amounts in pounds per square inch, except as modified in sections 6 and 18. These stresses, unless otherwise stated, are for steel having an ultimate strength of from 50,000 to 65,000 lb. per square inch. When other materials are used they shall bear the same proportion to the ultimate strength of the material used.

Bolster of rolled steel—Stress shall not exceed 12,500 lb. per square inch.

Sills and framing of rolled steel—Stress shall not exceed 16,000 lb. per square inch.

When cast steel is used the allowable stresses may be the same as for rolled steel, except tension stresses, which must be at least 20 per cent less than those for rolled steel as specified above.

For members in compression the stresses shall be determined by the following formula:

$$\text{Steel } 16{,}000 - 70\frac{L}{R}$$

In the above formula $L =$ length in inches.

$R =$ last radius of gyration in inches.

Shear,	other than buffing,	10,000 lb. per square inch
Bearing	other than buffing,	20,000 lb. per square inch
Shear, buffing,		12,000 lb. per square inch
Bearing, buffing,		24,000 lb. per square inch

The foregoing stresses are based on the assumption that the maximum end shock due to buffing shall be assumed as a static load of 400,000 lb. applied horizontally at the resultant line of the forces acting at the center line of the buffing mechanism and at the center line of the draft gear respectively, and shall be assumed to be resisted by all continuous longitudinal underframe members below floor level, provided such members are sufficiently tied together to act in unison. Calculations for resistance to buffing shocks shall be based only on underframe members below floor level.

These underframe members may be considered supported against buckling vertically by the superstructures between center plates at cross-bearers to the extent that the strength of the superstructure cross-bearers and attachments is available for that purpose.

For electric cars operated on lines where electricity is the only motive power, and the total weight of trains does not exceed 600,000 lb. the static load may be assumed to be 200,000 lb.

All connections, except those specified for end construction, shall be designed for the maximum load to which the member connected shall be subject; and secondary stresses in any members caused by eccentric loads shall be combined with the direct stresses in such members. The maximum fiber stress in any member subject to both direct and secondary stresses may be taken at 20 per cent greater than those given in section 20; but the direct stresses considered above must not exceed the allowable stresses.

With regard to vertical end members, the Postal specification requires:

> For electric cars operated on lines where electricity is the only motive power, and the total weight of trains does not exceed 600,000 lb., the sum of the section moduli of the vertical end members shall be not less than forty, and the section moduli of the main members, either forming or adjacent to the door posts, shall be not less than 75 per cent of this amount.
>
> The horizontal reactions of all vertical end members at the top shall be calculated from an assumed external horizontal force, applied 18 in. above floor line, to all vertical members in proportion to their respective section moduli, such force being of sufficient amount to cause bending of all vertical members acting together, and top connections of vertical end members shall be designed for their reactions. The bottom connections shall be sufficient to develop the full horizontal shearing value of such members.
>
> Except when vertical end members shall bear directly against or be attached directly to longitudinal members at either top or bottom, the assumed reactions shall be considered as loads applied to whatever construction is used at end sill or end plate, and both these last members shall have section moduli, respectively, sufficient to prevent their failure horizontally before that of the vertical end members.

Other specifications make allowance for oscillation, either by assuming as high as 25 per cent additional load or by reducing the allowable unit stress as low as 12,500 lb. per square inch.

The Postal specifications may be taken as representing good practice for electric car service as far as unit stresses are concerned, and also for buffing strains for cars in rapid transit service where speeds are high. For lower speeds and light trains the buffing strains may be reduced, as these will vary with the speed and with the energy of the moving mass. Thus if 200,000 lb. is considered to be sufficient for a maximum speed of 60 m.p.h., then for a city surface car whose speed will not exceed 15 m.p.h., the maximum end force would probably not exceed 12,500 lb., which for a car weighing 50,000 lb. with load is equivalent to a retardation rate of between 5 and 6 m.p.h.p.s., and would permit of approximately double that amount before the elastic limit of the material would be exceeded.

In the design of parts under compression particular attention should be paid to proper bracing, and in fact it may be

stated that, throughout, care must be taken that the structure is sufficiently rigid. It must be remembered that strength and rigidity are not necessarily synonymous, and the latter quality must be obtained by the proper reinforcement against buckling of parts in compression, and gusseting of joints subject to wearing action. On this point the Master Car Builders' Association has ruled that the length of center or draft-sill members between braces shall not exceed twenty times the depth of the members measured in the direction in which buckling might take place.

PART V

CAR EQUIPMENT

By C. W. Squier, Electrical Engineer

CHAPTER XXIV

CONSIDERATIONS IN THE CHOICE OF CAR EQUIPMENT

THE necessity for adequate means to meet present operating expenses which are mounting by leaps and bounds has made "efficiency" a watchword of all public utilities. The importance of what has appeared to the average official as dry technical calculations and uninteresting studies of operating requirements is so very great in the actual dollars and cents that can be saved and additional revenues that can be earned that the principles underlying them are now receiving increased attention.

In this and following articles on electric car equipment the writer does not claim to be developing any new principles. The material used and the facts brought out may be familiar to many railway engineers who are actively engaged in this work. Yet by a rearrangement and regrouping of the principles of operation and maintenance with a definite object in mind, it is hoped that certain of these fundamental requirements will be impressed more definitely in the minds of those most interested and prove an additional source of information and a benefit to the young men who are coming up in the electric railway field.

Comparison of First Car Equipments with Present. The equipment of the first electric cars was very simple, consisting only of a motor, controller, resistance and hood switch with the necessary wiring to connect the various parts. Contrast this with the equipment of the latest types of cars to-day. Motors have interpole and tap field windings and ventilated cores and windings for increasing their continuous capacity. Control equipments are arranged for multiple-unit operation with automatic and selective acceleration so that the acceleration of the car or train will remain constant regardless of the load. Current-limiting relays are provided which can be quickly adjusted to change the rate of acceleration to meet changes in service

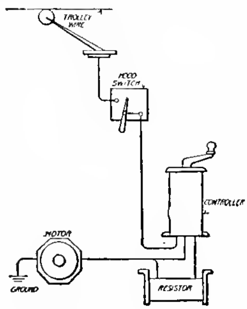
requirements. Electro-pneumatic brake equipments are used with quick recharge, graduated release and empty and load brake control so that the braking pressure will increase with the load, and thus maintain a constant rate of retardation. Automatic couplers are in use with main reservoir and train-line air connections made automatically and coupler slides with contacts for automatically making the electrical train-line connections between cars. Doors and steps are pneumatically operated and electrically controlled and their operation is interlocked with the signal system and main control connections so that the starting signal will not be given and the car cannot start until all doors are closed, and the doors cannot be opened till the car stops. Electric heaters are provided with thermostatic control, and coasting recorders or power recording meters are used to keep a check on the operation of the car.

From the foregoing comparison it is evident that an advance has been made toward automatic and power operation of all car parts; and there is no reason why a further elimination of manually operated devices should not be made. This permits the use of labor and cars that could not otherwise be employed in this capacity. Men can continue in the service longer, as age and physical weakness do not prove as great disadvantages as would otherwise be the case. The satisfactory use of women in car service as conductors in this time of great demand for labor has been made possible principally by power operated and automatic devices and the consequent reduction of the labor necessary on the platform so that the conductor becomes little more than a car cashier.

Another and greater advantage is the saving in time that can be effected by the use of power-operated devices. Other things being equal, anything that saves time is valuable to a railroad, since this is its chief purpose and service. Time saved by shortening the duration of stops is just as valuable as time saved during acceleration or retardation of the car. Napoleon regarded time as irreplaceable and of the greatest value. "Ask me," he said, "for anything but time." A saving in time increases the capacity or earning power of the road and also affords greater flexibility of operation and greater convenience to the traveling public.

The chief virtue and usefulness obtained from employing

electricity as a motive power for railroads lies largely in its convenience and its economy in the use of power. The more use that is made of this power, the greater the economy that can be expected. Railway officials in general have been eager for improvements as necessity demanded them, and not a few have been willing to try out new devices in the hope of bettering conditions. The argument that a new device is not necessary because we have hitherto been able to do without it is seldom ad-



SIMPLIFIED DIAGRAM OF CONNECTIONS IN EARLY CARS

vanced. It is obvious that if such an argument had been universally followed we would still be digging roots with our finger nails for a living.

A discussion of electric car equipment may be for convenience separated into the following parts:

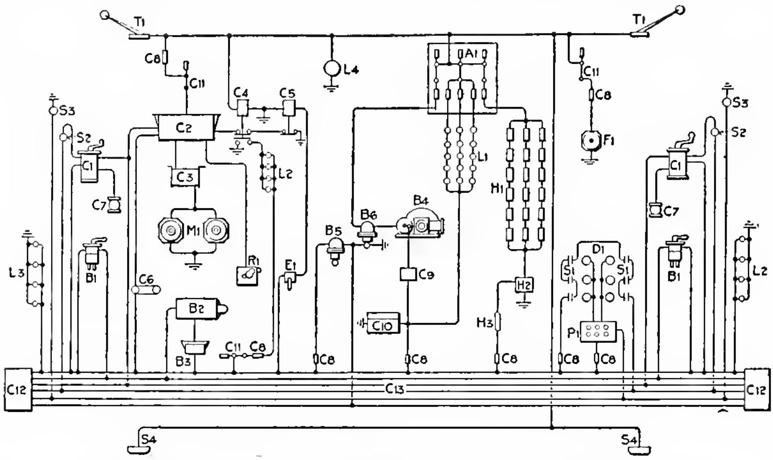
1. Determination of operating requirements.
2. Characteristics necessary to meet various classes of service.
3. Necessary details for proper installation.
4. Operation necessary for economy and safety, and
5. Inspection and maintenances practices.

The various parts comprising a complete car equipment may be logically divided into (a) those necessary for propulsion, (b) those used in braking, (c) auxiliary operating devices, and, (d) equipment for the safety, convenience and comfort of the traveling public.

Let us consider first those parts used in the propulsion of the car. As the motors are the heart of this equipment they will be discussed first.

Choosing a Motor Car for a Particular Service. In order

to choose a motor car intelligently for any particular requirements, we must first know just what service it will be called upon to perform, and what future requirements may be expected within the life of the equipment. This, then, requires an accurate knowledge of the present operating conditions and an estimate of the changes that may result from increases in population



LIST OF ELECTRICAL EQUIPMENT FOR LATEST TYPE CARS

A1—Switchboard
B1—Brake Valves
B2—Universal Valve
B3—Empty and Load Brake Attachment
B4—Compressor
B5—Master Governor
B6—Compressor Switch
C1—Master Controllers
C2—Unit Switch Group
C3—Resistors
C4—Line Relay
C5—Emergency Relay
C6—Selective Accelerating Device
C7—Dead Man's Control Valves
C8—Fuses
C9—Battery Charging Switch
C10—Storage Battery
C11—Knife Switches
C12—Electric Couplers
C13—Train Line
D1—Door Operators
E1—Emergency Trip Switch
F1—Ventilating Fan
H1—Electric Heaters
H2—Heater Switch
H3—Thermostat
L1—Main Lights
L2—Emergency Lights
L3—Head, Tail and Marker Lights
L4—Lightning Arrester
M1—Main Motors
P1—Push Button Box
R1—Coasting Recorder
S1—Door Signal Contacts
S2—Signal Lights
S3—Buzzer Signals
S4—Contact Shoes
T1—Trolleys

SIMPLIFIED DIAGRAM OF MODERN CAR CONTROL EQUIPMENT

and manufacturing industries necessitating a change in operating demands and lengths of lines. A large amount of this consists of data in connection with the character of the line and service which form a part of the records of most operating com-

panies. Additional operating data of the latest requirements should be obtained by a traffic survey. Methods for conducting such a survey and for collecting the desired data have been very fully treated in the article by J. F. Layng in the *Electric Railway Journal* of Jan. 5, 1918, but the list of headings given below for data desired will be found helpful.

Character of Line

Length of run.
Length of single track.
Length of double track.
Number of turnouts.
Distances between turnouts.
Length and percentage of heavy grades.
Number and radii of curves.
Length of congested sections.
Special characteristics.

Character of Service

Number of stops.
Number of slow-downs.
Length of stops.
Maximum speed.
Time for run.
Layover time.
Headway by periods.
Cut-offs.
Turn-backs.
Single car or train operation.
Lengths of rush-hour service.
Car-miles per day.
Car-hours per day.

Operating Data

Line voltage by sections.
Duration of "power" on period.
Duration of coasting.
Duration of braking.
Rate of acceleration.
Rate of braking.
Number of passengers on and off at each stop.
Maximum number of passengers on car at one time.
Congestion at terminals and transfer points.
Delays.

Car Equipment Data

Type of car.
Special features of car.
Weight of car.
Number and type of motors.
Type of control.
Hand or air brakes.
Type of trucks.
Diameter of wheels.
Gear ratio.

Trouble and Defect Record

Number of run-ins.
Number of cars held from rush-hour service.

The larger operating companies have engineers who are in constant touch with operating conditions and who conduct tests at intervals so that the data enumerated above are readily available. Manufacturing companies are usually willing to assist in conducting such tests in order to find out just how their equip-

ments are operating and for the information that they thus obtain to help in their calculations and designs for new equipment. Also if there is a prospect of securing an order for new equipment they are anxious to check conditions to make certain that any equipment ordered will fulfill the requirements. In addition to these sources there are, of course, consulting engineering firms which make a business of conducting tests and advising regarding specifications for new equipment.

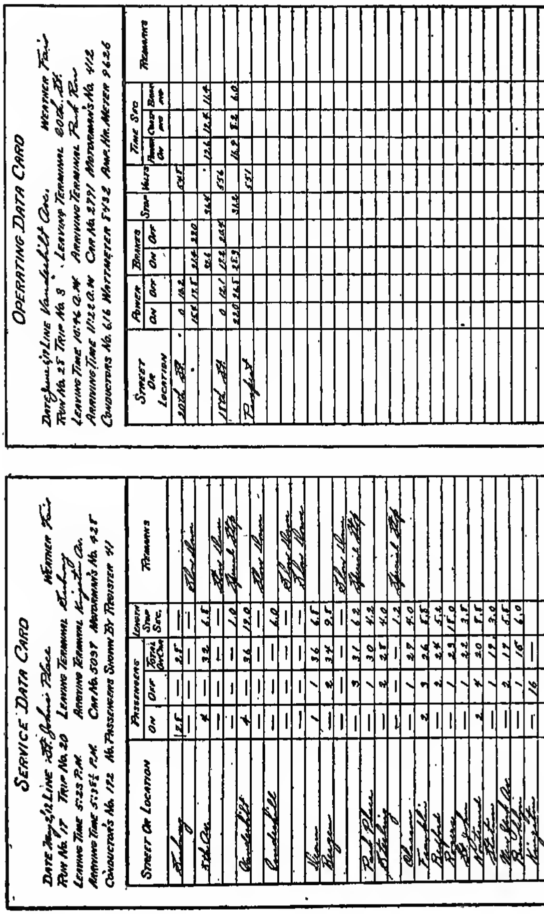
In making such a traffic survey it simplifies matters somewhat, and prevents duplicating information, if all data desired are taken at the same time, but this is not necessary if the tests extend over a considerable period. All the data on "character of service" for a specific line can be obtained and recorded by one man riding cars of that line. Three or four days' service should be sufficient in most cases. Another man can obtain all the operating data necessary.

The accompanying illustrations show two data cards that have been used by the writer on numerous traffic tests, and which satisfy all requirements. They have been kept as simple as possible in order to prevent confusion. The use of special men to obtain this information has been found more satisfactory than relying on conductors to fill out forms correctly. Another point the writer has endeavored to impress on those obtaining data is that if they miss a reading or neglect to record one they should not hesitate to make a note on the form to that effect and in no case enter figures that they have to estimate.

The man taking down the data as to character of service should be in a position where he can see and count readily all passengers boarding and alighting. This is done at each stop of the car. At the same time the length of stop is taken with a stop watch. Record is made of all slow-downs and their causes; also of any special stops or unusual occurrences that have a bearing on the service. At the beginning and end of the run he should fill in the following data as called for on the record card: Date, line, car number, run number, trip number, motorman's and conductor's numbers, leaving terminal, leaving time, arriving terminal, arriving time, weather and the number of passengers carried as shown by the fare register.

For obtaining operating data the car should have a voltmeter connected from the trolley pole to ground so that the line volt-

age can be read, and, if possible, a watt-hour meter and an ampere-hour meter. The man taking and recording the data takes a position where he can observe the operation of the car. With a split-second stop watch he takes the time during which power is on, and the time consumed in coasting and braking.



FORMS USED IN MAKING TRAFFIC SURVEYS

This is most readily done by starting the watch as the motorman applies power. Then by the use of the split-second hand he records the time that power is cut off and braking began. By stopping the watch as the car stops he has the complete cycle. The motorman may apply and cut off power several

times before he starts to brake or he may apply and release his brakes several times before he stops, but by recording the time that each different operation is begun the total time consumed in acceleration, coasting and braking can be readily computed. Voltage readings are taken at certain definite points along the run, and all high or low readings are recorded with their proper locations. Of course, a more extensive record can be obtained by the use of recording instruments. However, these suggestions presuppose that such instruments are not available, or that the time and expense of conducting a more elaborate test is not warranted. After the data cards for each trip are turned in they are summarized and the results thus secured are entered on the traffic data record.

CHAPTER XXV

BETTERMENTS AVAILABLE IN CAR EQUIPMENT

The spirit of the day is "economy" and "efficiency." Never before in our history have these two essentials been so impressed upon us. We have learned to retrench in fuel, food and all things connected with our daily needs as individuals, and we are learning to make what we have do twice the work we previously expected it would perform.

The cost of transportation is subject to the same rules as the cost of other commodities. Its cost of production must be restricted and reduced, and our car equipment so readjusted and operated that increased efficiency will result. In the past great strides have been made in rendering better service with lower costs of operation. Now any methods by which the capacities of our transportation system can be increased or their costs of operation reduced are of paramount importance.

Up to approximately five years ago safety and reliability in electric-car equipments were considered the first requisites. Heavy construction was considered necessary in order to meet the extremely trying operating conditions of railway service and to decrease the troubles of operation and the resulting maintenance costs. The life of all wearing parts was increased and operating engineers bent all their energies toward keeping maintenance costs as low as possible. As the limit in this direction was approached the fertile mind of railway engineers cast about for some other means of reducing costs of operation. Saving power appeared to offer the largest field for economy, as this constituted one of the largest operating cost items.

A demand for the reduction in weight of all car and equipment parts was the first that occupied attention. Articles were written by many engineers who figured the costs resulting from carrying around the dead weight of the car and its equipment. These figures varied from 3 to 10 cents per pound per year as the conditions and service varied. The results were, however,

that all manufacturers of railway equipment were forced to redesign their apparatus. By the use of high-grade metals, pressed-steel shapes and better insulation, the weight was reduced and at the same time other vital characteristics received careful study to reduce power consumption wherever possible. The results that have been obtained are astonishing and the limit has not yet been reached.

Let us consider the various groups of apparatus comprising a car equipment and see what improvements have been made that are conducive to energy and labor saving.

Making Better and Lighter Motors. As the motors are used for propelling the cars we naturally expect to find the greatest saving in energy through improvement in their design.

The saving in power, the greater electrical efficiency produced and the decreases effected in maintenance costs have resulted primarily from the following improvements:

1. Better mechanical and electrical construction.
2. More efficient methods of lubrication.
3. Slotted commutators and high-grade brushes.
4. Interpole field windings.
5. Self and forced ventilation.
6. Reduction in weight.
7. Higher grade insulation.
8. Choice of correct gear ratio.
9. Lower armature speed.
10. Tapped field windings.

After the experimental and early development stages of railway motor construction had passed, there followed the period, already referred to, when the energies of railway engineers were directed toward reliability and increased life in operation. This resulted in the development of the magnificent motor equipments that are now found on our electric roads.

The first two groups of improvements enumerated above belong to this period and need not be described here, as they are a matter of history which has been fully treated in many articles in the *Electric Railway Journal* and elsewhere.

Present 1500-Volt Motors Less Troublesome Than Old 500-Volt Types. The development of the interpole or commutating-pole motors was brought about in an endeavor to reduce op-

erating troubles and maintenance costs. This design was introduced and perfected during the period from 1907 to 1911. Previously one of the greatest troubles with direct-current motors was in commutation. The introduction of commutating poles, together with undercutting the mica of commutators and the use of high-grade carbon brushes which occurred about the some time, overcame this last serious objection.

Those who have had experience with older types of motors, especially before these improvements were adopted, will remember the frequency with which the commutators ran black and developed flat spots. The lathes in the maintenance and overhauling shops were kept in constant use turning down and sandpapering commutators. As a result commutator wear was very rapid and it was necessary for manufacturers to make the segments very deep to provide for this wear. Now the wear of commutators is so slight that it can hardly be detected after a year of service, and the depth of segments is made only sufficient for proper insulation and mechanical strength. The wear of the brushes was also very rapid, due to the excessive sparking at the commutator, and it was necessary also to use a brush with high abrasive properties to cut the mica. With the slotting of commutators hard brushes were no longer necessary and brushes with greater conductivity came into general use.

Another great advantage that has resulted from these improvements is in the use of higher voltage circuits, which has increased reliability of service. Now motors are made to operate on 1500 volts and have less commutator trouble and operate better than did the old motors on 500 volts.

The principal saving that has resulted from these improvements is in the reduced maintenance and repair costs which have been given by some reliable authorities as from 50 to 75 per cent. These improvements have also made possible the carrying of heavy overloads on the motors, permitting higher rates of acceleration and therefore more economical operation. They have also made possible the use of field control with its resulting economy.

The first railway motor did not have an enclosing frame. All parts were exposed and consequently well ventilated. Vital parts were easily damaged, however, and due to the exposed location of the motors it was found necessary to enclose all

parts by the frame. This added greatly to the reliability of the motor, but prevented proper ventilation.

As service conditions grew more severe it became evident that much could be gained by ventilating the interior parts and forcing air through the windings. The first step in this direction was to ventilate the armature and depend on its fan effect to keep the air circulating. This was a step in the right direction, but all heat had still to pass through the frame by conduction. By providing openings in the frame and additional ducts and channels in both frame and armature the present ventilated motor has been developed.

The various stages in the development in motor ventilation were shown very clearly by a series of diagrams in the *Electric Railway Journal* of May 15, 1915. On some locomotives air is forced through the motors by motor-driven blowers, but the construction most used provides a fan on the armature which draws air in and drives it through the armature and fields and by shields and ducts deflects it and again expels it to the outside of the motor. The effect that this has in reducing the temperature and increasing the capacity of the motors is simply tremendous, and it has resulted in increasing the continuous capacity of motors, which ordinarily is not more than 45 to 50 per cent of the one-hour rating, to 65 and 80 per cent of this rating.

The benefit that can be derived from self-ventilation depends upon the schedule speed that is to be maintained and the gear ratio used since the amount of ventilation obtained is a function of the armature speed rather than the car speed. Thus in city service much of the operation is at low speed, with the fan practically inactive, and the benefit derived will be comparatively small. In high-speed interurban service, with long runs, great benefit is obtained. With a separate blower for circulating the air the ventilation is, of course, independent of the speed.

Motor Weight Reduction Alone Can Save $42 per Car per Annum. The weight of motors has been reduced by careful designing and proper proportioning of parts so as to eliminate all useless material. High-grade metals have been used to a greater degree, and many parts formerly made of cast iron are now made of malleable iron or steel. Great improvements have been accomplished in making these steel castings so as to permit the

use of thinner sections than had been possible to cast theretofore. This has reduced the amount of useless material and resulted in a corresponding saving in weight.

Pressed-steel shapes have been used more extensively also, and heat treating of steel has been perfected to bring about other savings in weight. These improvements, together with the latest ventilating practice, have resulted in a saving of from 15 to 40 per cent in weight, as compared with the old-style, totally-inclosed motor. The exact percentage depends upon the commercial sizes and speeds available.

To take a concrete example, suppose we consider a two-motor equipment with old motors weighing 2700 lb. each replaced by motors weighing 2000 lb. each. This gives a saving in weight of 1400 lb. per car. At an assumed operating cost of 3 cents per pound per year there would result an annual saving of $42 per car per year. Now consider a road that is in the market for 200 new equipments. The reduction in the weight of the motors which this road could now purchase will represent a saving of $8400 per year.

Better Insulation is Equivalent to Increase of Motor Capacity. By employing a higher grade of insulation, with greater heat-resisting qualities, the capacity of motors has been increased through the raising of the safe temperature limit.

Soldering material with a higher melting point has also been used. This is important since heavy and sudden overloads of such short duration that they do not cause excessive heating of the armature coils, often last long enough to melt the soldered connections or to cause them to soften sufficiently to permit the solder to be thrown out by centrifugal action.

This increase in the capacity of motors will enable a lighter motor to be used for a given service and also will permit a higher rate of acceleration in operation, thus reducing the average power consumed.

Re-Gearing Costs Less Than 5 to 10 Per Cent Power Waste. The use of incorrect gear ratios for railway motor equipments has caused great losses to operating companies. Gearing that was suitable for operating conditions when the motor equipments were purchased will likely prove unsuitable as the service becomes more exacting. When we consider that in city and suburban service a majority of the work done by the motors

is at speeds less than 10 m.p.h., we begin to realize how important it is to be able to accelerate rapidly.

In checking over the service conditions of a large railway system operating city and suburban service, I find that 37 per cent of the total mileage made is in congested sections where a schedule speed of 7 m.p.h. is as high as can be obtained. Thirty-eight per cent of the mileage is in sections where from 8 to 9 m.p.h. is the highest speed practicable, and only the remaining 25 per cent is in sections where the cars can maintain a schedule speed of more than 10 m.p.h. The maximum speed for such sections is less than 11½ m.p.h. It is thus seen that the period during which cars can operate at maximum speed is very short, and a grave error is made by providing gearing for high speed when there is no opportunity to obtain it. A typical cycle for such service is rapid acceleration, short coasting period and rapid braking. Consequently the most efficient operation is with the lowest-speed gearing that will give the required schedule speed, with a reasonable margin for congested conditions and the making up of lost time.

Few outside of those who have made a special study of this question realize its importance and at the present time there are a great many motors operating in service which are so geared as to cause a continual loss to the operating company. Without doubt 5 to 10 per cent of all the power used for propelling electric cars and trains could be saved by the use of correct gearing.

In order that a motor may be economical in power consumption it must have a low armature speed, with as high a gear ratio as the service will permit. In comparing the power consumption of two motors, with the same gear ratio but different armature speeds, the one with the armature of lower speed will show a decreased power consumption in one of the following two ways, namely, it can produce the same rate of acceleration with less current, or with the same current it will give a higher rate of acceleration.

This saving will be found much more pronounced in a service with frequent stops. In comparing two equipments in a city service with nine stops per mile and a schedule speed of 9.2 m.p.h., it was found that the slow-speed motor used 0.46 kw.-

hr. per car-mile less than the high-speed motor, or a saving of 10.9 per cent in its favor. This was due to the more rapid acceleration of the car with the slow-speed motor, so that the accelerating current did not continue so long, and with the same amount of coasting the brakes were applied at a lower speed. Part of this saving is, therefore, due to lower rheostatic losses and the remainder to the smaller amount of stored energy wasted in braking.

How Field Control Saves $100 per 35,000 Miles. The first designs of double-reduction motors provided for controlling their speed by varying the effective turns in the field winding. This was known as the "loop" system and was quite familiar on our first electric roads. This method of speed control proved a failure at that time, due principally to the difficulties encountered in commutation as the fields were weakened.

Improvements in motor design, together with the use of interpole field windings, slotted commutators and high-grade carbon brushes, so improved commutation that railway motor designers have again taken up this method of control, with surprising success. The first method of field control consisted of shunting portions of the field windings through a resistance. The latest method differs from this in that, instead of shunting the field, approximately 40 per cent of the full field winding is cut out. The advantages gained by this latter method are that the use of a non-inductive shunt around the field is avoided. This, with solid-frame motors, produced flashing.

Let us consider how a tapped-field motor saves power, and what saving can be expected by the use of tap-field control. This saving in power is the result of more efficient acceleration. By comparing the characteristic curves of the motors, one a slow-speed motor without field control and the other the corresponding motor with field control, we find that the speed of the field-control motor, when operating on normal or tapped field is about the same as that of the other motor, while the speed of the field control motor when operating with full field is much lower.

In accelerating the full field is used and the rheostatic losses will be less, as the grid resistors have less resistance and are not in circuit for as long as is necessary when using a motor with-

out field control. The tapped field is used for running, so that the same speed is obtained as with the non-field-control motor and the braking losses remain the same. A further advantage is also obtained by use of the field-control motors when the same car is required to operate in service of different character. Thus for combined city and suburban service field control provides more economical operation over the slow-speed city sections in that it permits the use of a gear ratio most economical for this service, and with the same gear ratio provides the higher speed necessary for suburban service.

As an illustration of the saving that may be expected from the use of tapped-field motors consider a two-motor equipment where the tractive effort per motor necessary to produce the desired acceleration is 2000 lb. The relative values of current necessary to give this tractive effort are 83 amp. with the non-field-control motor as compared with 76 amp. with field control, and the corresponding rheostatic losses are 1.4 watt-hr. per ton as against 0.7 watt-hr. with field control. The tapped-field motor, then, saves 0.7 watt-hr. per ton every time the car starts. With a car weighing 30 tons and making eight stops per mile the saving in rheostatic losses alone will amount to 0.168 kw.-hr. per car-mile. The total saving from employing field-control motors in the service will amount to 0.38 kw.-hr. per car-mile. Considering that energy costs 3/4 cent per kilowatt-hour at the car, and assuming that the car makes 35,000 miles per year, this saving would amount to approximately $100 per car per year.

Concentrating Control Saves Weight, Wire and Conduit. At the same time that new motors were being developed, the old ones were receiving much attention from operating engineers and master mechanics with a view to cutting down maintenance costs. Wonders have been performed in this field, and now it is essential as never before to introduce still further economies if profits are to be made by the average road.

The design of railway control apparatus has kept pace with the improvements in motor construction and many operating economies have been made possible by the advance made in control equipments. The following are some of the improvements in control that have aided in producing high service efficiency and operating economies:

1. Simplicity of construction.
2. Greater reliability.
3. Consolidation of parts into single units.
4. Reduced weight.
5. Improved materials.
6. Automatic acceleration.
7. Selective acceleration.
8. More efficient use of resistance.
9. Arrangement for field control.

One of the most notable advances has been the tendency to seek simplicity and reliability and to combine various small pieces of apparatus into larger units. In the equipment for surface cars a return has been made to more general use of the shunting method of transition from series to parallel, instead of using the bridging feature, which required a great number of contacts or switches. These changes are producing lower maintenance costs and reduced cost for replacement parts.

The combining of various pieces of control apparatus and assembling them in a single box, which applies particularly to switch-group control, simplifies the control connections, reduces the labor and time of inspection and provides a lighter equipment.

Switch Group of World's Biggest Rapid-Transit Car Weighs Only 900 lb. The effort to reduce weight has not been confined to car bodies, trucks and motors, but has been extended to control equipment in a marked degree The consolidation of various parts comprising an equipment into single units, just referred to, has produced astonishing results in weight reduction. In the control equipments used by the New York Municipal Railway on their new subway cars, the switch group which is designed to handle two 200-h.p. motors weighs but 900 lb., scarcely more than half the weight of the former control outfit of similar capacity.

By combining all the main-circuit apparatus in a single box a further reduction in weight has resulted, due to the decrease in the amount of cable and conduit required and in the labor and consequent cost of installation.

Another marked saving in weight has been effected by a special design of grid resistor, whereby the weight of a set has

been reduced approximately 40 per cent without loss in continuous capacity.

Not only has the weight of resistors for a given capacity been decreased by better ventilation and increased radiation, but control connections, also, have been rearranged so that the same section of resistance is used several times in increasing the voltage on the motors, by using it in series and again in parallel with other sections. Previously when a section was cut out it remained inactive during the remainder of the period of acceleration. This improvement gives a more efficient use of the resistors.

Smaller Control Accelerates Passenger Interchange. A large part of the equipments now being supplied are of the switch-group or multiple-unit type of control. Some of the many advantages possessed by this type of control are:

1. Better location of apparatus.
2. Less platform space occupied.
3. Less liability of accident.
4. Greater flexibility for operation.
5. Decreased maintenance.
6. Automatic acceleration.

The removal of the controller from the platform is important because the greater the space that can be used for boarding and alighting the less will be the resulting congestion and the shorter will be the stops. This produces a saving in time that is at once apparent in the increase that results in schedule speed, while the saving in platform wages and passenger time is well worth considering.

This effect of the length of stop on operating results and costs is very clearly illustrated in the article by J. F. Layng in the *Electric Railway Journal* for Jan. 5, 1918. This shows an increase of one-third in the cost of platform wages alone by increasing the duration of stop from five to fifteen seconds with nine stops per mile.

The removing of the main circuit apparatus from the car platform reduces the liability of accidents from controller explosions and burnouts, with consequent reduction in accident damage suits.

Automatic Acceleration Promotes Faster Schedules. An-

other great saving is possessed by switch-group control arranged for automatic acceleration in that it eliminates the energy waste in the first or accelerating part of the operating cycle by removing the personal element in operation.

Designing engineers make very careful calculations for the values of the various resistance steps in order to obtain smooth acceleration and prevent abnormal current peaks. They assume a certain definite rate of notching for cutting out these resistance steps. With hand-operated controllers this is seldom obtained.

The effect that the rate of notching has on current values and power consumption is very clearly shown by the curves given in my article on "Resistance Standards" in the issue of the *Electric Railway Journal* for May 11, 1912. A saving of from 5 to 7 per cent in the total power used could be obtained on most roads if the controllers were operated according to the methods assumed in the design of the apparatus. Automatic acceleration does away with the personal element and assures the engineer that the equipment will be operated as desired.

Another saving with automatic acceleration is in obtaining at all times the maximum rate of acceleration for which the equipment is designed. It is frequently found that where a line is operating under a fairly easy schedule the motorman will accelerate slowly and, no doubt, operate with the motors in series a large part of the time. A study of the energy required for different rates of acceleration is very interesting. With a specific equipment operating in city service the following results were obtained:

Rate of Acceleration M.p.h.p.s.	Watt-Hours per Ton Mile	Per Cent Saving from ¾ m.p.h.p.s.
¾	110	
1	90	18.2
1¼	83	24.5
1½	78	28.2
2	76	30.9

The difference in energy saving is considerably less between the high rates of acceleration than it is between the low rates. Thus the difference between accelerating at 1½ and 2 m.p.h.p.s. is only 2.7 per cent, while between ¾ and 1¼ m.p.h.p.s. it is 24.5 per cent.

Selective Acceleration Is Another Refinement. In order to obtain the same rate of acceleration for all loads between maximum and minimum, what has been termed selective acceleration has been developed. On the subway cars of the New York Municipal Railway this is accomplished by having two windings on the limit switch. One coil is in series with the main motor circuit, while the other is wound so as to oppose the first and is connected to a storage battery through a variable resistance. This resistance is cut out automatically as the load on the car increases, so that it will take more current through the series winding to counteract the current in the battery circuit and therefore to cause the "limit" to operate.

This feature not only produces economy at the car but permits trains to get away from stations faster and makes them respond more rapidly at signals, thereby increasing the capacity of the road.

Another great advantage accomplished by this improvement is in connection with field control. In changing from full to short field with tapped-field motors there is a sudden increase in current. This current swing mounts very rapidly as the lower current value, from which the change is made, is increased. Thus if the change from full to tapped field is made at 200 amp. the current will increase to 340 amp., and if it is made at 275 amp. it would swing to 450 amp. By the use of the double winding on the limit switch, just described, this change is always made at the lowest setting of the limit switch, which is 200 amp., and this current swing is constant and moderate.

Faster Braking Results in Energy Saving. Time saved while stopping a train is just as valuable as time saved during any other part of the operating cycle. Improvements in air brakes have made it possible to use a higher rate of retardation for stopping and also they have reduced the time necessary to apply the brakes so as materially to reduce the stopping distance and time necessary for bringing a train to rest.

Conditions remaining the same, any increase in the braking rate produces a decrease in power consumption, since the car or train can be allowed to coast longer and the brakes can be applied at a lower speed. Thus less of the stored energy of the car will be consumed during the braking period. This

saving is shown directly in the decreased time that power must be used in order to maintain the required schedule speed.

Electro-Pneumatic Brakes Stop a Train in 330 ft. Instead of 580 ft. By using electricity to actuate the air valves of the compressed air brake, the following advantages have been obtained:

1. The difference in time, at which brakes are applied on the front and rear cars of a train is eliminated.
2. The probability of rough handling is reduced.
3. The difference in time between the movement of the brake valve and the application of the brakes is reduced.
4. Brake-cylinder pressure and the resulting retarding force is developed more rapidly.
5. Higher rates of retardation can be employed.
6. The limits in the length of trains are removed.

The largest saving that has been accomplished by the use of electro-pneumatic brakes has been obtained by increasing the braking rate. Previously it was not possible to use a rate of retardation anywhere near approaching the holding power between the wheels and the rail. This was due to the fact that in applying the brakes pneumatically the application began first at the front end of the train, and this interval between brake application at the front and rear prevented using the maximum rate of retardation at the front end or shocks would occur so severe as to damage the car equipment and be injurious to passengers. By the use of the electro-pneumatic features a rate of initial retardation has been made possible at least ten times that formerly used without damage or inconvenience, since the brakes are applied on the rear of the train at nearly the same instant as at the front.

It is also practicable to use a maximum rate of retardation approaching very closely to the holding power of the rail. Compared on this basis, brakes applied electro-pneumatically will give 100 lb. brake cylinder pressure in two seconds, with a braking ratio of 150 per cent, and will stop a train from 40 m.p.h. in 330 ft., while when applied pneumatically they produced 60 lb. cylinder pressure in 6.6 seconds, a braking ratio of 120 per cent and at 40 m.p.h. required 580 ft. to stop the train. A saving in distance of 250 ft. is obtained in this instance by

the use of electro-pneumatic brakes. This means a great deal on lines where it is necessary to operate to the full capacity of the tracks, as the length of the blocks used in signaling depends on the distance that is necessary to bring a train to a stop. With shorter blocks trains can follow each other more closely and so the capacity of the line is increased.

The stopping distance with the pneumatic brake will increase as the length of train is increased, while that with the electro-pneumatic brake is independent of train length. The length of train that can be operated is thus limited by the use of the pneumatic brake, while with electro-pneumatic brakes any length trains are feasible as far as the brakes are concerned.

The value of increased braking rates on electric cars or trains makes itself manifest in a decreased power consumption if the same schedule speed is maintained or in an increase in schedule speed with the same power consumption. This follows since, with the same schedule speed, an increased rate of retardation will allow an additional amount of coasting and enable current to be cut off the motors sooner. The energy saved in average city service by increasing the rate of retardation from 1 to 1½ and 2 m.p.h.p.s. will average about 8 and 11 per cent respectively.

Since a high rate of retardation produces the greatest economy it is desirable to maintain the maximum rate with a loaded car or train as well as with a light one. A braking power sufficient for a light car is inadequate for one loaded, and if the braking power is designed so as to use the adhesion of the loaded car it would obviously produce sliding wheels when the car is empty. The variable-load brake, which has had its first installation in passenger service on the cars of the New York Municipal Railway, fulfills this requirement.

On these cars a full passenger load represents 45 per cent of the light weight of the car. The increase in train weight if the same braking pressure were used would mean practically a proportional increase in braking distance. It will be readily appreciated that the improvement prevents a serious waste of time and decreases the distance between trains at limiting points so as to increase the capacity of the lines

Briefly, this automatically provides an increase in brake-

cylinder pressure as the load increases, by increasing the volume of the auxiliary reservoir. This change in reservoir capacity is accomplished by the use of an additional reservoir divided into compartments of various sizes, and connected to the auxiliary and supplementary reservoirs through ports controlled by a slide valve. The movement and position of this slide valve is automatically adjusted by the variations in weight on the truck springs due to changes in passenger load. An accurate adjustment of braking power in ratio to load is thus obtained.

In some tests made under operating conditions with a view to determining what saving was effected by the use of this improvement in stopping loaded trains, it was found, with the brake-cylinder pressure adjusted to give the maximum safe rate of retardation for a light train, that in making a stop with a fully loaded train from 40 m.p.h. an additional five seconds per stop and an average of 150 ft. in stopping distance was required over that obtained with the empty-and-load device supplying a brake cylinder pressure in proportion to the load. This means that with a brake adjustment and pressure for producing an average rate of retardation of 2 m.p.h.p.s. with a light train, there would be obtained but 1.6 m.p.h.p.s. with a fully loaded train. By the use of the empty-and-load brake device 2 m.p.h.p.s. could be obtained.

This device also improves operation in that a motorman can judge his stopping distance more accurately, for the stopping distance with the same reduction in train line pressure will be nearly constant, while otherwise motormen frequently have to make a second reduction and sometimes an emergency application.

Slack Adjusters for Safe Saving—Automatic Couplers for Quick Train Make-Up. Slack adjusters also decrease power consumption. In making an application of the brakes, the first movement of the brake-cylinder piston takes up the slack in the brake rigging and brings the brake shoes in contact with the wheels. The more slack there is in the brake rigging the greater is the distance that the piston will have to travel before braking pressure is applied to the wheels, and the greater will be the volume of air used in applying the brakes. By taking up any excessive slack in the brake rigging the slack adjuster aids in

giving more efficient braking. Slack adjusters also lengthen the period between brake adjustments.

The most important recent developments in coupler design include provision for automatically making the air and electrical connections between cars as well as providing the mechanical coupling of the cars. These improvements effect a great saving in time in adding and cutting off cars and they also do away with the extra men formerly necessary to assist the motorman in making these connections. Accidents are also reduced to a minimum. Automatic couplers also make it easy to add and cut off cars at points before the end of the line is reached, so that trains of maximum length can be operated through the congested service sections and then cars can be cut off and the remainder of the run made with just enough cars to take care of the service requirements.

Pneumatic Door and Step Control—Better Lighting with Large Units. With power operation of doors and steps, many advantages have been made use of to reduce costs that were not considered at first. These include:

1. Reduced number of accidents.
2. Shorter duration of stops.
3. Better car heating.
4. The use of labor more suitable for personal contact with the traveling public.

When the rear platforms of earlier cars were open no door-operating mechanism was necessary, but with the introduction of closed vestibules on cars it became evident that the value of such cars would be greatly increased by a faster operation of door and step mechanisms. The earning power and attractiveness of a car are also greatly increased by the use of automatic equipment.

The hard service which manual door operation requires of a conductor can be appreciated from the fact that on some lines a round trip requires opening and closing the doors as many as 200 times. Is it any wonder that with hand-operated doors the conductor slows up his operation after a few trips?

I have already discussed the advantage in power saving that is gained by keeping the stops as short as possible. There is an additional advantage obtained by closing the doors quickly

in the saving of heat in cold weather. In addition to these savings in time and labor, power operation of doors and steps permits the use of a different class of platform labor and assists in obtaining it more readily, as the duties are made more attractive and desirable. Labor with greater mental capacity rather than physical agility can be used, and as the duties require close and continual contact with the traveling public better relations are fostered and complaints are reduced in number.

The changes and improvements that have been made in car lighting have resulted not only in better lighting but in cheaper lighting as well. The lamps in use on cars on nearly all the lines today are of the improved tungsten-filament type. Up to approximately five years ago the carbon-filament lamp was in general use. Due to the fact that nearly all roads using direct current arrange their lamps in circuits of five lamps in series, and as these circuits are subjected to a considerable fluctuation in voltage, the carbon lamps used were burned at low efficiency. Tungsten-filament lamps outclass carbon lamps in efficiency and in the color of the light produced and, with the improvements in manufacture that have been made, they now give as long life as the carbon lamps.

The first use of tungsten-filament lamps was in replacing carbon lamps and as most of these installations had been arranged for use of 16-candle power lamps these were replaced with 23-watt tungsten lamps to give approximately the same illumination. In rearranging lighting circuits for remodelled cars and installations of new equipment an endeavor has been made to use a lamp of larger candle power with fewer units per car, in order to get the durability of a larger filament. The results of some tests extending over a period of several years after carbon lamps had been replaced with tungsten-filament lamps show a net saving in the cost of energy after the additional cost of tungsten lamps reinstalled had been deducted of 25 cents per 1000 car-miles.

The advantages of the electric heater result from light weight, smaller fire risk, low maintenance, reliability, possibility of accurate regulation, cleanliness and small space required. The operating cost of electric heating is a serious one and this fact has been especially emphasized during the past winter.

Thermostatic Control Saves Money. The use of thermostatic

control for regulating the electric heaters of cars has produced a large saving. Careful observations taken in actual service have shown that this saving amounts to 30 to 40 per cent of the total power used for heating in some cases. The heat from the passengers' bodies aids in heating the cars more than is usually supposed. A crowded car is many degrees warmer than an empty one consuming the same current.

During the rush hours cars traveling in one direction are usually crowded while those going in the opposite direction are comparatively empty. These varied conditions can be met successfully only by having an accurate automatic control of the heaters. The heating current load, occurring as it does during the winter months when both the lighting load and the power load are increased considerably, is worth more than its proportion of the total cost of power. The "top of the peak costs most" and any reduction in heating current decreases the peak load.

CHAPTER XXVI

SERVICE CONDITIONS DETERMINE CAR EQUIPMENT CHARACTERISTICS

In the previous chapter I gave an outline of the data that are desirable to determine service conditions, and some suggestions as to the best methods for obtaining these data. Let us now consider a particular service and make use of these data to determine the motor equipment best suited for the requirements.

How Number and Duration of Stops Vary with Service. I have chosen for consideration first a city and suburban service and the data I shall use are from actual tests made on a large system operating this service. In making these tests twenty of the most important lines were chosen as being representative of the entire system, and a traffic survey was made of these lines. In tabulating the results for the summarized data record, each line was divided into sections and the data have been tabulated for each section. By this method we have been able to determine accurately the service characteristics of the various districts as well as the requirements for the complete line. A comparison of the results of these tests indicates that this service in most cases is made up of four distinct classes as follows:

1. At the ends of the lines there are runs of from 1½ to 2½ miles in length through a suburban district where the stops average from five to six per mile. These stops are of comparatively short duration due to the small number of persons boarding and alighting at each stop.

2. Another class of service is through a more closely populated residence section with stops of from seven to nine per mile, with some transfer points and with a corresponding longer time for stops.

3. The next class is operation through a business section where the stops average from twelve to sixteen per mile and where the headway between cars is so short, due to several lines

TRAFFIC DATA RECORD

Line	Section	From To	Class of Service	Length of Run, Miles	Per Cent of Total Mileage	Average Schedule Speed M.P.H.	Average Number Stops per Car-Mile	Average Length Actual Stops Seconds	Average Number Passengers on for Day	Maximum Number of Passengers on Car One Time	Maximum Number Passengers Carried Any One Trip
No. 1	A	Ridge—Ralph	2	1.086	16.8	8.23	8.05	9.58	23	62	68
	B	Ralph—Birch	2	3.185	49.7	8.55	8.34	6.60	35	84	127
	C	Birch—Water	3	0.607	9.3	5.40	16.50	7.54	22	63	67
	D	Water—Terminal	4	1.570	24.2	9.90	2.12	8.26	18	66	67
	E	Ridge—Termioal Av.	Av.	6 448	Total	8.25	6.96	7.04	26	66	145
No. 2	A	Depot—Twentieth Avenue	1	1.566	19.0	11.40	3.87	6.72	5	35	36
	B	Twentieth Avenue—Atlantic	2	3.997	48.6	8.90	6.90	7.82	28	98	109
	C	Atlantic—Water	3	1.105	13.1	6.70	11.80	8.94	24	101	116
	D	Water—Terminal	4	1.589	19.3	8.90	2.40	5.68	17	59	59
	E	Depot—Terminal	Av.	8.257	Total	8.90	6.94	7.99	33	101	127
No. 3	A	Sixteenth Avenue—Church	1	0.593	6.1	11.70	5.58	7.89	19	36	49
	B	Church—Reed	2	4.725	48.5	10.70	7.64	6.73	24	54	69
	C	Reed—Plaza	3	2.852	29.3	7.14	11.75	7.07	24	70	86
	D	Plaza—Terminal	4	1.550	16.1	12.36	1.32	6.63	10	34	40
	E	Sixteenth Avenue—Terminal	Av.	9.720	Total	9.45	8.00	7.41	27	55	101
No. 4	A	Prospect—Avenue X	1	12.50	2.01	12.28	4.54	7.15	7	18	20
	B	Avenue X—Plaza	3	3.505	56.2	7.60	13.54	7.31	20	78	108
	C	Plaza—Terminal	4	1.478	23.7	12.55	1.25	4.06	16	63	63
	E	Prospect—Terminal	Av.	6.233	Total	9.46	7.55	7.09	18	78	108

operating over the same tracks, that there is very little operation beyond the series position of the controller. Frequent slow-downs for traffic also add somewhat to the congestion.

4. The last class of service involves entering and operating across bridges which have severe grades at each end and where

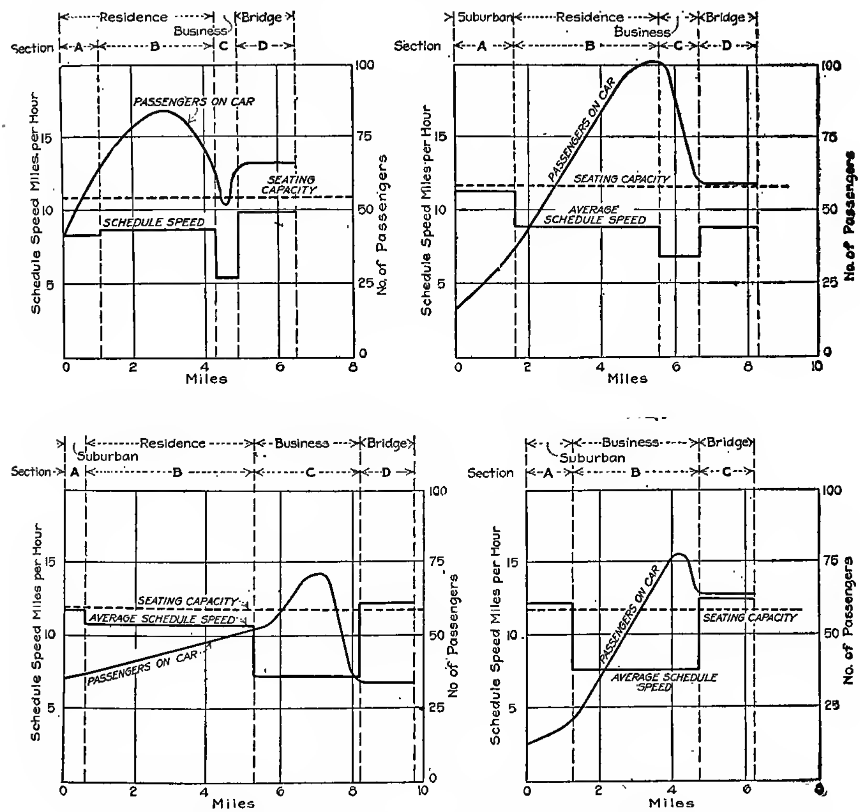


FIG. 34—GRAPHS SHOWING CAR LOADING IN DIFFERENT ZONES FOR FOUR TYPICAL LINES

the only stops are due to congestion of traffic. The length of these runs is from 1 to 1½ miles in each direction.

In the accompanying "Traffic Data Record" I have shown this summarized record for four of these lines. This will illustrate how the data were separated for each line so as to show average results for each class of service.

The columns on passenger loads give some very good information as to districts where passengers are picked up and discharged and the average loads carried throughout the various sections of the line. In order to illustrate this more clearly I have plotted graphs showing the average number of passengers carried in the different zones for the four lines given in the table and have also indicated the seating capacity of the cars operated and the average schedule speed that is maintained.

It should be borne in mind that these represent average and not maximum conditions, and also travel in both directions through the various sections.

A further comparison of the different classes of service is obtained by averaging the results from all lines with the data divided and tabulated as follows to show average requirements for each class of service:

SUMMARY OF SERVICE TESTS

Class of Service	Per Cent of Total Mileage	Average Schedule Speed M.P.H.	Average Number Stops per Car-Mile	Average Duration of Stop, Seconds
Suburban	12	11.3	4.4	7.2
Residence	38	8.7	8.1	7.2
Business	37	7.3	12.4	7.6
Bridges	13	10.9	2.7	6.6

In the column showing the percentage of total mileage operated in each class of service it is seen that the mileage for suburban operation is practically the same as for bridge operation, these being 12 per cent and 13 per cent of the total mileage respectively. Also the mileage operated in residence districts is nearly the same as that operated in business districts, these being 38 per cent and 37 per cent respectively of the total mileage, or about three times that operated in suburban and bridge service. The highest schedule speed obtained was 11.3 m.p.h. in suburban service with an average of 4.4 stops per car-mile of 7.2 seconds each, while the lowest schedule speed through business districts was 7.3 m.p.h. with an average of 12.4 stops per car-mile of 7.6 seconds duration. This average number of stops per car-mile includes slow-downs; it being assumed that two slow-downs are equal to a stop. The average length of stop is very uniform, this varying only from 6.6 to 7.6 seconds.

Operating Characteristics Show Schedule Speed as Affected by Stops. From these data I have plotted an operating characteristic graph, Fig. 35, showing the variation in schedule speed with the number of stops made per mile. By referring to this figure it is seen that the schedule speed varies from 7.3 m.p.h. with a stop every 425 ft. to 15 m.p.h. with stops every 2600 ft. Such a graph plotted from the service conditions on any road will be found very useful for comparing the different equipments operated. We can now use this curve for the preliminary selection of motors upon which to base our calculations in choosing new equipment.

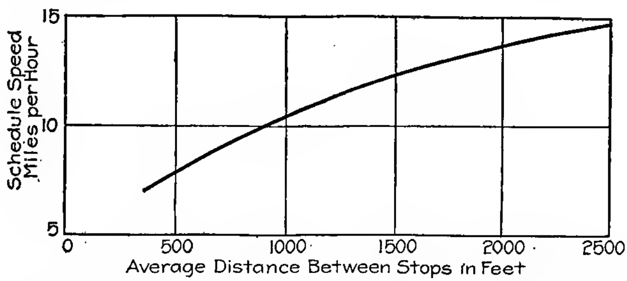


FIG. 35—VARIATION OF SCHEDULE SPEEDS, WITH NUMBER OF STOPS

Our first problem in connection with the choosing of the motor equipment of a car is to lay out a duty cycle from the service requirements, with certain preliminary assumptions as regards weight of the car, desired rates of acceleration and retardation and a decision for our first calculations as to the number of motors per car to be used. I shall later make some comparisons to show the relative advantages possessed by two- and four-motor equipments, but for the preliminary study we shall assume two motors per car.

In the preliminary calculations for any proposed equipment, speed-time curves with the current and energy consumption curves form the basis for calculating the performance of the equipment and give the first start toward making the selection of the motors to be investigated for capacity as limited by heating. There are a number of things to be considered in the selection of a motor for a given service. The most important requirement is that the motor chosen must be capable of performing the required service without becoming overheated.

The amount of heating in service is determined by the "square-root-of-the-mean-square" motor current and the average voltage on the motor. In the service which we are considering, a long series of tests has shown the average line voltage at the cars to be 540 volts.

OPERATION WITH SINGLE CARS

Weight of car	39,000 lb.
Seated load fifty-eight passengers	8,120 lb.
Standing load 130 passengers	18,200 lb.
Average line voltage from test	540 volts
Diameter of driving wheels	28 in.
Number of motors per car	2
Average length of runs:	
Suburban	1,200 ft.
Residence	658 ft.
Business	427 ft.
Average	620 ft.
Bridge runs will be studied in detail.	
Average duration of stop:	
Suburban and residence	7.2 sec.
Business	7.6 sec.
Average	7.3 sec.
Schedule speed:	
Suburban	11.5 M.P.H.
Residence	9 M.P.H.
Business	7½ M.P.H.
Bridges	12 M.P.H.
Average	9 M.P.H.
Accelerating and braking rates	1½ M.P.H.P.S.
Train resistance	Use curve from actual tests
Curve resistance	8 lb. per ton per degree of curvature

Speed in m.p.h. on curves to be limited to the square root of the radius in feet.

DATA FOR DUTY CYCLE AND SPEED TIME CURVES

Speed at crossovers not limited.

A tractive effort of 100 lb. to be used for accelerating 1 ton at a rate of 1 m.p.h.p.s.

Again the motor should be able to make the desired schedule speed safely and, in addition, it should have some additional capacity and speed for making up lost time. The maximum attainable speed, however, should be kept as low as is consistent with the above condition, and the gear ratio chosen should be such that when the car is running at its maximum speed, the motor armature speed will not exceed a safe limit.

Motor Capacity Theory and Practice Can Be Brought into Close Agreement. A number of articles have appeared in the *Electric Railway Journal* from time to time giving methods of calculating the performance of railway motors while operating under service conditions. It is possible, however, that the degree of accuracy with which a service may be predetermined is not very generally understood. By checking preliminary calculations with actual results taken from tests, railway engineers have reached a stage where it is possible to choose the equip-

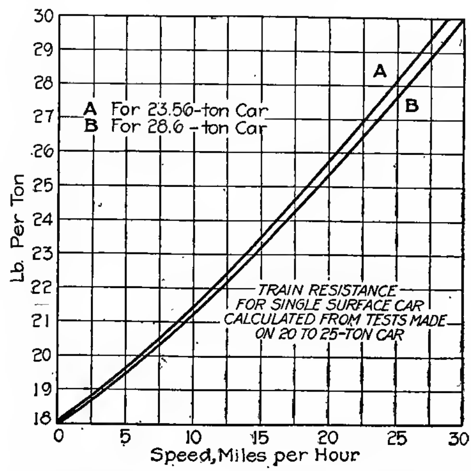


FIG. 36—TRAIN RESISTANCE FOR SURFACE CARS

ment and be certain that it will fulfill the required conditions. So close agreement has been established between theory and practice.

In these preliminary calculations it is usual to simplify the work somewhat by substituting a uniform grade for the irregular profile of the road. This uniform grade is taken as the average of the various grades between terminal points. In the present service I intend to treat the bridge runs where the most severe grades are encountered separately, while the average grade for the remainder of the service is so small that it may be neglected in the first calculations. Curve resistance and the effect of curves on the speed is usually averaged in laying out the typical run except in districts where these occur so frequently and are so severe as to require low-speed running.

Instead of figuring out each individual run for a car or train making frequent stops, the service is studied by typical runs equal in length to the average distance between stops for the service under consideration. Some discretion has to be used in applying these methods as they do not hold good over too wide limits, but with precautions they will produce accurate results.

In order to apply this method to the study of the service selected for illustration the data in the accompanying table will be used.

Numerous empirical formulas have been developed for train resistance, some of them based on very elaborate tests. The values obtained by the use of these formulas differ widely. The two graphs shown in Fig. 36 are derived from a series of tests which I made on surface cars of from 20 to 25 tons weight operating on city service. Since making these tests I have had occasion several times to check these with the results of other tests in similar service. I find that they compare very closely with results obtained. To adapt these data to calculations where the weight of the cars vary slightly from the ones actually tested, I have worked out the following empirical formula:

$$F = 18 + 0.3V + 0.1\frac{V^2}{T}$$

when F = train resistance, pounds per ton
V = speed, miles per hour
T = weight of cars in tons

This formula for train resistance, worked out graphically in Fig. 36, should be used only for single-car operations on surface tracks and for cars corresponding closely in weight to those tested.

CHAPTER XXVII

PROPER ANALYSIS IS FUNDAMENTAL IN CHOOSING RAILWAY MOTORS

Railway motor characteristic curves show speed in miles per hour with a certain gear ratio and size wheel, tractive effort at the rim of the wheel and efficiency. The efficiency is usually expressed as the relation between the electrical input to the motor and the mechanical output from its armature shaft. By deducting the losses in the gears connecting the armature shaft with the car axle, we obtain the relation between the electrical input to the motor and the output at the rim of the car wheels. This relation is referred to as "efficiency with gears" and is the one most generally used, although it is desirable to have both given in order to eliminate errors made by determining gear and friction losses by different methods.

Motor characteristics form the basis of all calculations of motor performance, and in comparing motors for a particular service it is usual to replot the curves as furnished by the manufacturer, making any changes necessitated by any difference in voltage, gear ratio or diameter of driving wheels. The following formulas give the various changes in speed and tractive effort as effected by a change in gear ratio or diameter of wheels:

S = Speed ordinate for any current value on original curve.
S_1 = Speed ordinate for any current value on derived curve.
T = Tractive effort for any current value on original curve.
T_1 = Tractive effort for any current value on derived curve.
D = Diameter in inches of driving wheels for original curve.
D_1 = Diameter in inches of driving wheels for derived curve.
G = Gear ratio for original curve.
G_1 = Gear ratio for derived curve.

Then:

$$S_1 = \frac{(G \times D_1)}{(G_1 \times D)} S \text{ and } T_1 = \frac{(G_1 \times D)}{(G \times D_1)} T$$

For example, suppose we have the characteristic curve for a motor with 33-in. wheels and 15:69 = 4.6 gear ratio and we wish to find the derived curves for 30-in. wheels and 17:67 = 3.94 gear ratio.

$$\text{Speed ordinate } S_1 = \frac{4.6 \times 30}{3.94 \times 33} S = 1.061S \text{ and}$$

$$\text{Tractive effort ordinate } T_1 = \frac{3.94 \times 33}{4.6 \times 30} T = 0.942T$$

The factors by which the speed and tractive effort at any current are to be multiplied to give the derived values are the reciprocals of each other. It should also be noted that in changing the gear ratio on the same motor, the sum of the number of teeth in the pinion and gear must remain the same.

The voltage at the terminals of a railway motor may be divided into two parts, the counter-emf. and the voltage required to overcome the internal resistance of the motor. This last component is equal to the product of the resistance in ohms by the current in amperes and is thus constant for any given current regardless of the terminal voltage. In a certain 50-hp. motor with a resistance of ½ ohm 20 volts are necessary to force 40 amp. through the windings, and for any other current the value will be proportional.

The speed of a railway motor when operating with any given current is directly proportional to its counter-emf., that is, the voltage produced by the armature conductors cutting the magnetic flux.

Thus,

$$\frac{S_1}{S} = \frac{E_1 - Ir}{E - Ir}$$

where

E is the terminal voltage for the original curve
E_1 is the terminal voltage for the derived curve
I is the current value
and r is the internal resistance of the motor

If the 50-hp. motor referred to above is operating at 40 amp. and 600 volts, the voltage required to overcome the internal resistance is 20 and the counter-emf. is 580 volts. If the voltage at the terminals is reduced to 500, with the same current, the counter-emf. will be 480 volts and the speed of the motor will be reduced in the same proportion. The ratio of 480 to 580 is 0.827 and if the speed at 600 volts was 17 m.p.h., it would be reduced to 14.06 m.p.h. at 500 volts. It is thus seen that the speed is reduced in greater proportion than the terminal voltage, for the ratio of 500 to 600 is 0.833. It follows, then, that if the resistance of a motor is known, the characteristic curves at any desired voltage can be readily calculated from the curves available.

Some graphical methods for determining the speed ratio for different changes in terminal voltage were given in the issues of the *Electric Railway Journal* for March 13 and September 18, 1915, and serve to illustrate these relations very clearly.

The tractive effort produced by the motor is independent of the voltage, being determined by the current alone. Hence, as long as the motor is drawing a given current the torque and resulting tractive effort will be essentially the same regardless of the voltage at its terminals.

Speed-Time Curves Show Motor Performance for a Particular Service. Before making a comparison of the service furnished by different motors, I shall discuss briefly a method for calculating and constructing the speed-time curves. Data for the duty cycle are given in the previous chapter and in the *Electric Railway Journal* of April 20. The characteristic curves of a tapped field motor, to be used in the present calculations are shown in Fig. 37-A.

In starting a car resistance is placed in series with the motors, and this is gradually cut out by the action of the controller until finally the full line voltage is applied to the motors. This period of the operating cycle is known as the rheostatic accelerating period. Assume an average acceleration for this

period of 1½ m.p.h.s. To produce an acceleration of 1 m.p.h.p.s. requires 100 lb. per ton, so that 150 lb. per ton will be required to give the acceleration desired. As the car with seated load weighs 23.56 tons, there must be 150×23.56 or 3534 lb. net tractive effort for the car or 1767 lb. per motor to give the required acceleration. In addition to this, the motor must produce the tractive effort necessary to overcome the train resistance, as shown by the graphs shown in Fig. 36.

In order to determine the point on the speed-time curve at which all of the starting resistance is cut out and the motors have full line voltage applied to them, it is most convenient to use an auxiliary curve sheet of the form shown in Fig. 37-B.

This method was first brought to my attention in an article by W. S. Valentine in the *Street Railway Journal* of Sept. 6, 1902. It has been described several times since in various handbooks and technical papers.

These graphs, Fig. 37-B, are constructed as follows: A scale of pounds net tractive effort per motor is laid off along the horizontal axis and scales of speed and acceleration are laid off along the vertical axis. The train resistance graph, *RR,* is first plotted, showing train resistance per motor for the different speeds. The graphs of net tractive effort, *LS* and *MN,* are obtained by taking the tractive effort at any speed from the motor characteristic curves, Fig. 37-A, and subtracting the train resistance for that speed from this.

Thus at 12 m.p.h. the tractive effort with full field is 1060 lb., less 262 lb. train resistance, which leaves 798 lb. net tractive effort. These values are then laid off and the point *P* on the graph is determined. Other points are obtained in a similar manner. With tapped-field motors two graphs are obtained as shown. Since the rate of acceleration is directly proportional to the net tractive effort, a straight line drawn through zero at the proper angle will be the graph of acceleration on straight level track. In our case it required 1767 lb. per motor to give an acceleration of 1½ m.p.h.p.s. This locates the point *Q,* and the line *OQ* gives the acceleration for different values of net tractive effort. From the curve *LS* we see that 1767 lb. net tractive effort is obtained at a speed of 9.9 m.p.h. Hence the car will accelerate at the rate of 1½ m.p.h.p.s. until this speed is reached, when full line voltage will be applied to the motor.

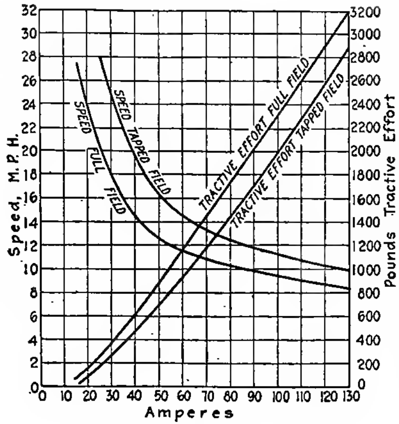


FIG. 37-A

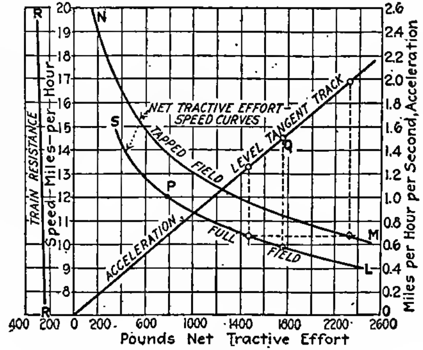


FIG. 37-B

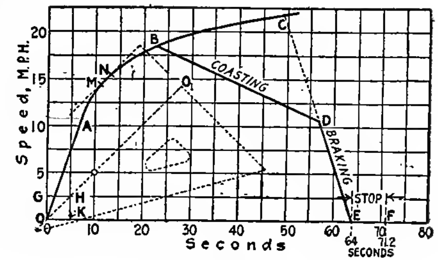


FIG. 37-C

FIG. 37—GRAPHS USED IN SPEED-TIME-CURVE CONSTRUCTION

Fig. 37-A—Typical Motor Characteristic Curves

Fig. 37-B—Acceleration and Tractive Effort Graphs

Fig. 37-C—Typical Speed-Time-Curve Construction

There are many graphical methods used for plotting speed-time curves, and all possess considerable merit. My experience has shown that the step-by-step process gives a clearer understanding than others of the actual mechanics of car performance and a firmer grasp on the theory underlying the construction of the curves. After such an understanding has been obtained graphical methods are of great assistance in reducing the labor involved, especially when it is necessary to plot many curves.

In the following table are tabulated values for each step of the speed-time-curve construction. As the motor characteristic curves give tractive effort for a single motor it is more convenient to figure the pounds train resistance and net tractive effort per motor instead of per car.

	Per Motor					
Miles per Hour	Amperes	Tractive Effort	Train Resistance	Net Tractive Effort	Rate of Acceleration	Seconds from Start
9.9	90 F.F.	2,018	251	1,767	1.50	6.6
10.35	80 F.F.	1,735	253	1,482	1.26	6.93
10.35	120 T.F.	2,580	253	2,327	1.98	6.93
11.00	106 T.F.	2,160	256	1,904	1.62	7.29
12.00	88 T.F.	1,660	261	1,399	1.19	8.00
13.00	74 T.F.	1,300	265	1,035	0.87	8.97
14.00	64 T.F.	1,040	270	770	0.65	10.29
15.00	57 T.F.	870	275	595	0.51	12.01
16.00	51 T.F.	750	280	470	0.40	14.23
17.00	47.5 T.F.	650	286	364	0.31	17.09
18.00	44.5 T.F.	580	292	288	0.245	20.70
19.00	42 T.F.	510	297	213	0.180	25.41
20.00	39 T.F.	460	303	157	0.134	31.78

A speed of 9.9 m.p.h. corresponds to a current of 90 amp. I have assumed a lower current limit setting of 80 amp. so that the motors operate with full field until the current falls to this value, when the change to tapped field is made. This will occur at a speed of 10.35 m.p.h. as will be seen from the characteristic curves, Fig. 37-A.

To construct the speed-time curve of Fig. 37-C, we use the figures in the table as follows: As the car accelerates at a rate of 1½ m.p.h.p.s up to 9.9 m.p.h., the time required to reach this speed is $9.9/1.5 = 6.6$ seconds. This determines the point A on the curve, and the line OA represents the straight line or rheostatic accelerating period.

As the car increases its speed the current, tractive effort and rate of acceleration decrease and at a speed of 10.35 m.p.h. the current will have fallen to 80 amp. and the rate of acceleration will be 1.26 m.p.h.p.s. Since the tractive effort and acceleration decrease uniformly as the car increases in speed, we may assume without serious error that the average acceleration during this period is the average of the initial and final accelerations. The average rate of acceleration between 9.9 and 10.35 m.p.h. is ½ $(1.5 + 1.26) = 1.38$ m.p.h.p.s.

In using this method speed intervals greater than 3 m.p.h. should not be used. Usually an interval of 1 m.p.h. will be found very convenient. To increase the speed from 9.9 to 10.35 m.p.h., a difference of 0.45 m.p.h., at a rate of 1.38 m.p.h.p.s. requires $0.45/1.38 = 0.326$ second, and the car reaches the speed of 10.35 m.p.h. in $6.6 + 0.326 = 6.926$ seconds from the start. This gives another point on the speed-time curve, and at this point the change from full to tapped field is made, and a sudden increase in acceleration takes place. This increase in acceleration can best be followed by referring to the graphs shown in Fig. 37-B. From an acceleration rate of 1.26 m.p.h.p.s. with a net tractive effort of 1482 lb. on full field we reach 2327 lb. net tractive-effort and an acceleration of 1.98 m.p.h.p.s. with tapped field. A study of these graphs shows the desirability of limiting the current swing when changing to tapped field. Above this point the values of tractive effort are taken from the tapped-field tractive-effort curve. At 15 m.p.h. the current is 57 amp., the tractive effort 870 lb. per motor, the train resistance 275 lb. per motor and the net tractive effort $870 - 275 = 595$ lb. per motor. Therefore the rate of acceleration at 15 m.p.h. is 595/1178 or 0.505 m.p.h.p.s. Other points are found in the same manner and the curve *AC* is thus determined.

Short-Cuts in Making Speed-Time Curves. In order to save time and labor in constructing speed-time curves I make use of several modifications of the preceding methods and the following has been found especially convenient:

By taking speed intervals of 1 m.p.h. and by assuming that the acceleration for any speed starts ½ m.p.h. below and continuous for ½ m.p.h. above this speed, we can omit figuring the time given in the table preceding. To illustrate this let us take the speed of 15 m.p.h., with its corresponding acceleration

of 0.505 m.p.h.p.s. as found above. The slope of the speed-time curve through 15 m.p.h. is determined by drawing the line OO_1, starting from O and passing through the 5.05 m.p.h. point at 10 seconds. This corresponds to an acceleration of 0.505 m.p.h.p.s. To plot the curve take a triangle and lay one edge along the line OO_1, then slide the triangle along so as to draw the line MN for the speed-time curve parallel to OO_1, starting at 14½ m.p.h. and continuing to 15½ m.p.h. The slope for the acceleration at 16 m.p.h. starts at 15½ m.p.h. and continues to 16½ m.p.h. and so the curve is constructed with short straight lines. This provides a very rapid as well as accurate method of constructing the curve.

What Coasting and Braking Periods Mean. The speed-time curve as calculated so far shows the performance of the car while the motors are propelling it. In order to stop at a given point power must be shut off and the brakes applied. To complete the coasting and braking periods of the speed-time curve consider a run of 1200 ft. at a schedule speed of 11½ m.p.h. with a 7.2 second stop. The time required to make such a run will be $(1200 \times 3600) \ / \ (5280 \times 11.5) = 71.2$ seconds. This time includes the 7.2 second stop, so that the running time, not including stop, is 64 seconds. An average braking rate of 1½ m.p.h.p.s. was specified. To construct the braking part of the curve, start at the 64 second point on the base line and draw a line through the 15 m.p.h. point at 54 seconds. The slope of this line will then be correct for the braking rate assumed. This line cuts the accelerating part of the curve at C. The curve $OABC$ is the accelerating portion with power on, CE is the braking line and EF is the top.

The Area Under the Speed-Time Curve Is a Measure of the Distance Traveled. The distance which the car travels is most conveniently found by measuring the area under the speed-time curve. To illustrate how this area is a measure of the distance traveled, let us consider one of the cross-section squares. The area of such a square is 2½ m.p.h. $\times$ 5 seconds, and if the car could be started instantly at a speed of 2½ m.p.h. and run for 5 seconds and then stopped instantly, the speed curve would be the square $OGHK$ and the car would have traveled $(2.5 \times 5280 \times 5) \ / \ 3600 = 18⅓$ ft. Each of three squares, therefore, represents 18⅓ ft. As the car is to travel 1200 ft., for this run

the area under the speed-time curve must be $1200/18\frac{1}{3} = 65.46$ squares.

The part of the curve *OAB* with power on, *DE* the braking line and *EF* the stop, are fixed so that the only part that can be varied to get the correct area is the position of the coasting line *BD*. This is first drawn in a trial position and the inclosed area is obtained by counting the squares or measuring with a planimeter. If the area is found too great, the coast line is moved down, and if too small, the line is moved up and this cut and try method continued until the inclosed area is found to be correct.

To determine the slope of the coasting line, take the train resistance for the average coasting speed and compute the rate of retardation from this. In Fig. 37-C, the average speed for the coasting line *BD* is 14½ m.p.h., the train resistance is 275 lb. per motor and the rate of retardation $275/1178 = 0.23$ m.p.h.p.s., that is, 10 seconds after power has been shut off, the speed of the car will be reduced 2.3 m.p.h. This method assumes that the coasting line is straight, which is not entirely correct, since the train resistance varies with the speed of the car and the coasting line will have a slight curvature. This curvature is so small, however, that no serious error is introduced by assuming the coasting line as straight and the slope drawn to correspond with the train resistance at the average speed.

CHAPTER XXVIII

CURRENT AND POWER CURVES SHOW RESULTS TO BE EXPECTED OF MOTORS

Having determined the speed-time curve, as outlined in Chapter XXVII, the curves for current and power input are readily obtained. By referring to the characteristic curves of the motor given in connection with the previous article it is seen that with the same voltage the speed is always the same for any definite current value. With the series-parallel method of control, now universally used with direct-current railway motors, the motors are first connected in series and then in parallel when two-motor equipments are used. With four-motor equipments the most common practice is to connect the motors in groups with two motors permanently in parallel. These groups are connected first in series and then in parallel. With the two-motor equipment we are considering, from the start until the motors are connected in parallel the car current is equal to the current per motor, which is 90 amp., the current necessary to give an acceleration of 1½ m.p.h.p.s. With the motors connected in parallel, the car current will be double the current per motor, or 180 amp. This is shown graphically in Fig. 38.

To determine the point in the speed curve at which the transition from series to parallel takes place, we use the relation between speed and terminal voltage as discussed in the article referred to above. This change will be found to take place at a speed of 4½ m.p.h.

In order to plot the part of the current curve after the starting resistance is all cut out, it is only necessary to plot the current value corresponding to any speed at the instant that this speed is reached, as shown by the speed-time curve. In the case we are considering the current per motor is 90 amp. up to a speed of 9.9 m.p.h. At 10.35 m.p.h. the current with full field has fallen to 80 amp. and the change to tapped field is made.

This increases the current per motor to 120 amp. From this point on the current values corresponding to the various speeds, as shown in the following table, are plotted. When a speed of 18½ m.p.h. is reached power is shut off and the current falls to zero.

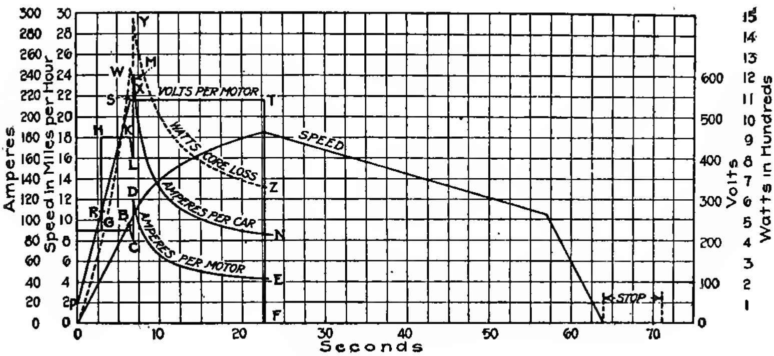


FIG. 38—GRAPHS FOR CURRENT AND CORE LOSS PER MOTOR AND AMPERES PER CAR

SPEED, CURRENT AND POWER CONSUMPTION

M.p.h.	Seconds	Amperes per Motor	Amperes per Car	(Amperes)^2 per Motor	Watts per Car at 540 V.
4.5	3.0	90	90	8,100	48,600
9.9	6.6	90	180	8,100	97,200
10.35	6.93	80	160	6,400	86,400
10.35	6.93	120	240	14,400	129,600
11	7.29	106	212	11,236	114,480
12	8.00	88	176	7,744	95,040
13	8.97	74	148	5,476	79,920
14	10.29	64	128	4,096	69,120
15	12.01	57	114	3,249	61,560
16	14.23	52	104	2,704	56,160
17	17.09	47.5	95	2,256	51,300
18	20.70	44.5	89	1,980	48,060
19	25.41	42	84	1,764	45,360
20	31.78	39	78	1,521	42,120

The average current taken by the car is found by dividing the area of the car-current curve in ampere-seconds by the time for the run, including the duration of stop in seconds. In Fig. 38, the graph *OAGHKLMNF* shows the current taken by the car. Each cross-section square with reference to this curve is equal to $20 \times 2\frac{1}{2} = 50$ amp.-sec. When measured with a planimeter this curve was found to have an area of 55.9 squares,

hence the average current per car for this run is $(55.9 \times 50) \div 71.2 = 39.25$ amp. The average current per motor, obtained from the graph *OABCDEF* in a similar manner, is 21.5 amp. The heating of railway motors in service is caused by internal copper, iron and brush losses. These losses vary in intensity and in distribution with different types of motors and classes of service. To determine whether a motor has sufficient capacity for a particular service, a curve should be plotted from the squares of the various current values and from this the square-root-of-the-mean-square current should be obtained. This should not exceed the rated continuous current of the motor for the average voltage found. For convenience the motor characteristic curves furnished by manufacturers usually give the continuous rating in amperes at half, three-fourths and full voltages. With modern self-ventilated motors this root-mean-square current practically determines the temperature of the motor, since the increased speed that goes with higher core losses also causes a better circulation of air through the motor and causes the dissipation of more heat.

In Fig. 39-A the graph *OPXYZMN* has been plotted from the squares of the instantaneous current values. The area under this graph, which can be conveniently measured with a planimeter, is 11.06 squares, equivalent to 110,600 (ampere)^2-seconds. The mean-square current is found by dividing this area in (ampere)^2-seconds by the time for the complete run, including the duration of stop in seconds or $110{,}600 \div 71.2 = 1553$. Then by taking the square root of this mean-square value we have 39.4 amp. for the square-root-of-the-mean-square current. The continuous current rating of this motor is 40.5 amp., so that we find this motor has sufficient capacity for the given service. The average voltage for each motor is found from the curve *OPRSTF* (Fig. 38) to be 470. The voltage curve is constructed by drawing a line through *R* (270 volts at 3 seconds) and *S* (540 volts at 6.6 seconds) and then using the average line voltage of 540 for the remainder of the time that power is on. The area of this curve is 85.54 squares or 10,692.5 volt-seconds, which divided by 22.75 seconds, the time that power is on, gives 470 volts as the average that is applied to each motor during the run.

Core Losses Are Determined by Tests. Fig. 39-B shows

graphs for the iron and core losses for this motor. These losses depend on both the current and the voltage. They follow no simple law as do the copper losses, which are proportional to the square of the current.

Owing to the great mass of metal in its frame, a railway motor has considerable heat storage capacity. When the temperature of the windings is rising that of the frame must also be increased, and when cooling the entire mass must cool off nearly simultaneously. The actual temperature of the different parts may, of course, be widely different but due to this action of storing heat, the temperature of the windings does not fluctuate rapidly in accordance with the instantaneous losses,

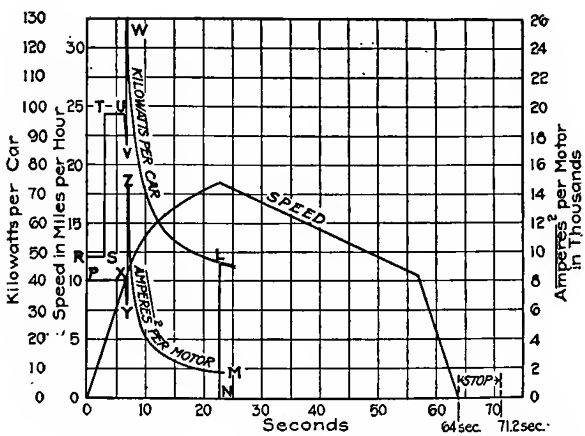


Fig. 39-A—Graphs Showing Heating Current per Motor and Kilowatts per Car

but rises at a fairly uniform rate depending on the average value of these losses. The average core loss for any typical run may be obtained by plotting the curve $OWXYZF$ as shown in Fig. 38, giving the core loss in the motor corresponding to the instantaneous values of voltage and current. To illustrate the method of plotting this curve, let us find the point on the core-loss curve at ten seconds after the start of the run. From the curves showing current and volts per motor it is found that at the ten-second point there are 66 amp. and 540 volts per motor. Then from the graphs shown in Fig. 39-B, we find the core loss corresponding to this current and voltage to be 1020

watts. This value plotted at the ten-second point in Fig. 38 will be the desired point in the core-loss curve. The average core loss for the run is then obtained by dividing the area under this curve in watt-seconds by the total time for the run, including stop, or 71.2 seconds. This gives 245 watts as the average core loss. The power-input curve is constructed from the car-current curve by multiplying the various current values by the

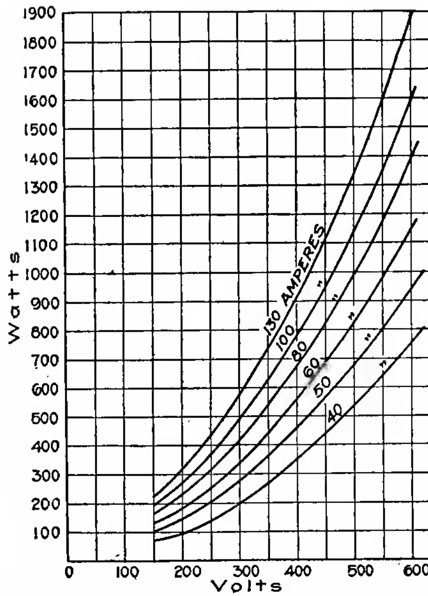


FIG. 39-B—GRAPHS INDICATING THE CORE LOSSES IN MOTOR

average line voltage. In the table preceding, I have tabulated the various power values in watts corresponding to different current values and in Fig. 39-A the curve *ORSTUVWLN* shows this graphically. By measuring the area under this curve and by computing the values as described previously we find that 0.42 kw.-hr. is taken by the car for this run.

In considering various types of motors for operation in the same service with cars of the same weight, a comparison can be made directly from the results shown while performing the various typical runs representing average service requirements. When it is desired to compare equipments on the same cars, or

on cars weighing nearly the same but operating at different schedule speeds, such a comparison as the preceding would probably be misleading and unfair to the equipments under consideration, since the above average values are dependent on the speed at which the car travels. A fair basis of comparison in such cases is found in the values expressed in kilowatt-hours per car-mile. The present figure of 0.42 kw.-hr. was for a run 1200 ft. long made in 71.2 seconds, hence the energy input is $(0.42 \times 5280) \div 1200 = 1.848$ kw.-hr. per car-mile.

When it is desired to compare the performance of equipments on cars with considerable differences in weight, the units of watt-hours per ton mile should be used as a basis of comparison. This unit takes into consideration the difference in weight as well as any difference in schedule speed. The weight of the car with equipment and load which we are considering is 23.56 tons and $(1.848 \times 1000) \div 23.56$ gives 78.4 watt-hours per ton-mile as the energy consumption.

In making comparisons all the associated conditions and the quantities affecting them should be carefully considered and taken into account and a unit for comparison chosen which will be fair to the equipment being considered and not be misleading as to the results that may be expected.

CHAPTER XXIX

EFFECT OF GRADES AND CURVES IN PLOTTING SPEED-TIME GRAPHS

At the beginning of this discussion on the preliminary calculation necessary in choosing car equipment I called attention to the fact that it is usual to assume a typical run for studying the various characteristics of the equipment. Different typical runs representing the service under consideration have been worked out and the procedure necessary for calculat-

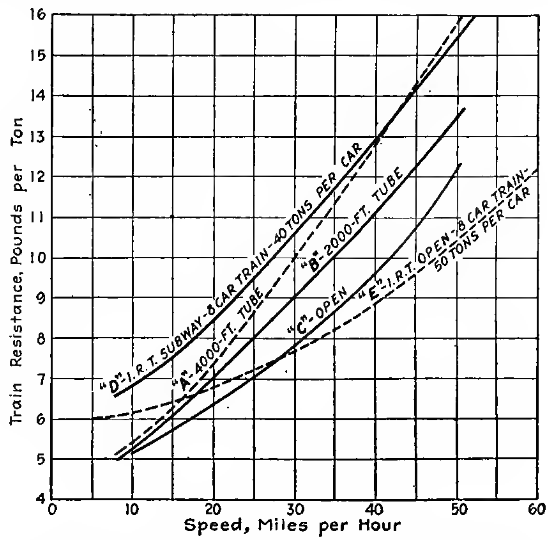


FIG. 40—GRAPHS OF TRAIN RESISTANCE
A, B, and C, from Tests on the Hudson & Manhattan Railroad. D. and E, from Tests on the Interborough Rapid Transit Subway

ing and plotting the various graphs has been described. All this, however, has been done for a level tangent track. There are times when a proper study will necessitate taking into consideration the individual runs as they are actually made with due regard to the curves and grades encountered. Such studies

of operation are absolutely necessary when determining the maximum capacity of a certain section of track, that is, the greatest number of cars or trains that can be operated through a given section per hour or during any given time interval.

Also in laying out signals it is necessary to know the speed at various points and this, of course, will be affected by the grades and curves of the line. Problems of this nature are continually occurring in the work of the operating engineer, and while it is not usual to go into this great detail in choosing the car equipment, still a knowledge of the factors involved is essential.

I shall describe briefly the calculations and methods most generally used in determining speed-time, distance-time and speed-distance curves when all variations of grade and curves are taken into consideration. As the graphs for current and power input are derived curves the methods already described for obtaining these will apply here also.

To illustrate this I have chosen an express run from Union Square to Canal Street in the new Broadway subway in New York City, with train make up and equipment as shown in Table I.

TABLE I—OPERATING CONDITIONS FOR PLOTTING SPEED-TIME GRAPH

Number of cars in train	8
Total length of train	536 ft.
Weight of car as equipped	89,000 lb.
Weight of passenger load per car (200 passengers at 140 lb. each)	28,000 lb.
Total weight of car with load	117,000 lb.
Motor equipment, G.-E. 248-A motors per car	2
Gear ratio	61:22
Diameter of wheels	32 in.
Train resistance from tests in service (See Fig. 41, Curve D)	
Curve resistance per degree of curvature	0.8 lb. per ton
Average line volts	500
Average accelerating current per motor	290 amp.
Average braking rate	2 m.p.h.p.s.

The speed in miles per hour on curves is limited to the square root of the radius of the curve in feet, and this speed is not exceeded until the last car of the train is off the curve. This is the usual assumption for the safe maximum speed while

rounding curves and is limited by the elevation of the outside rail. Easements are considered as having a radius of twice that of the curve having the easement. A speed of 15 m.p.h. must not be exceeded by the train while taking crossovers, as superelevation cannot be provided at these points.

The motors used are arranged for tapped-field control, and the change from full field to permanent field is made when the current drops to 200 amp. This takes place at a speed of 16.7 m.p.h. The current swing is from 200 amp. to 337 amp. and the tractive effort from 2870 lb. to 4750 lb. The run is made

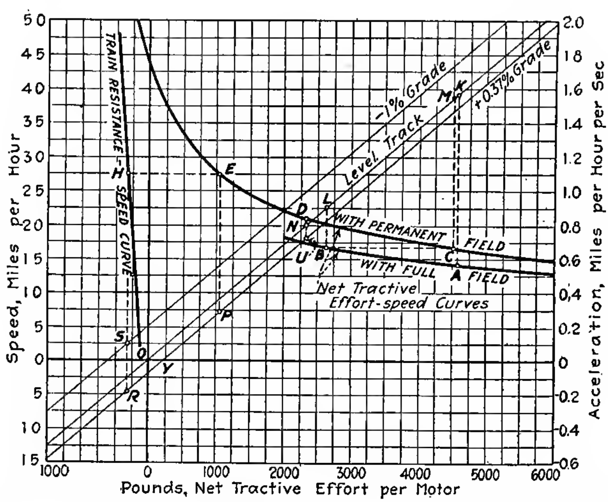


FIG. 41—GRAPHS FOR PLOTTING SPEED-TIME CURVES WITH VARIOUS GRADES AND CURVES

at the highest possible schedule speed. The amount of coasting and braking is limited to that necessary for slowing down the train whenever short-radius curves, steep down grades or cross-overs make this necessary. In order to conform to actual operating conditions four seconds are allowed from the time the motorman drops off power and starts to apply the brakes to the instant that the braking rate of 2 m.p.h.p.s begins.

Fig. 42 shows the completed speed-time, distance-time, speed-distance and power-input graphs for this run. The profile and alignment for the track are included for convenience in

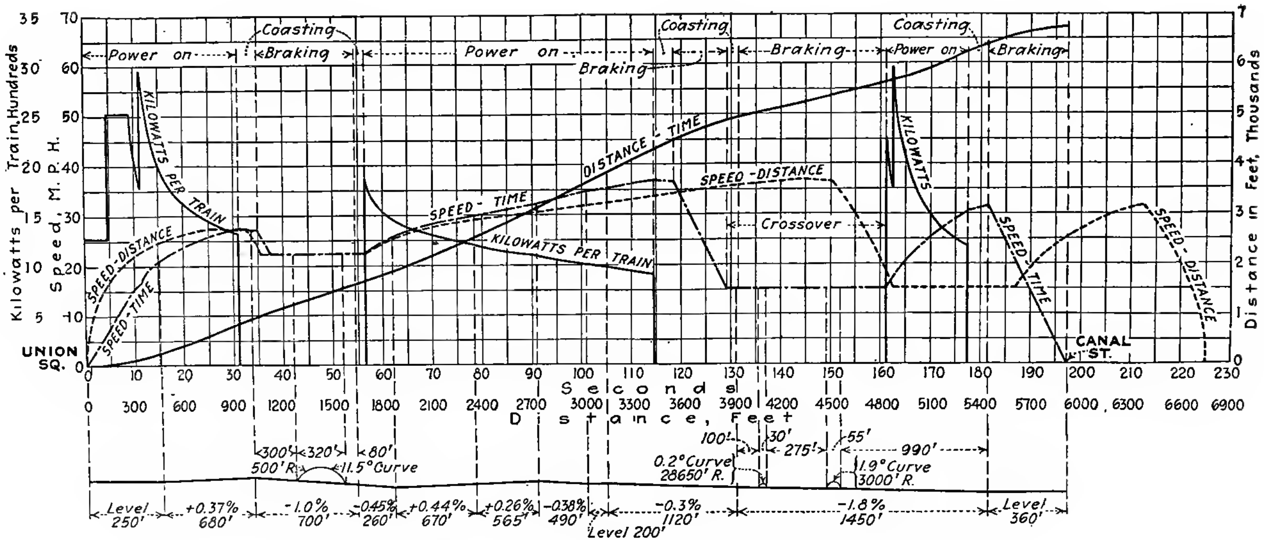


Fig. 42—Speed-Time, Distance-Time and Speed-Distance Graphs

TABLE II—VALUES OF DIFFERENT QUANTITIES FOR EACH STEP OF SPEED-TIME CURVE CONSTRUCTION

		Per Motor										
Speed, m.p.h.	Amperes	Tractive Effort, Pounds	Grade, per Cent	Grade Resistance, Pounds	Curve, Degrees	Curve Radius, Feet	Curve Resistance, Pounds	Train Resistance, Pounds	Total Resistance, Pounds	Net Tractive Effort, Pounds	Rate of Acceleration or Retardation, m.p.h.p.s.	Distance from Start, Feet
6.4	290	4,800	Level	...	Straight	Straight	...	...	...	....	...	...
14.2	290	4,800	Level	...	Straight	Straight	...	218	218	4,582	1.57	...
16.7	200	2,870	Level	...	Straight	Straight	...	228	228	2,642	0.91	...
16.7	337	4,750	Level	...	Straight	Straight	...	228	228	4,522	1.55	...
18.0	295	3,900	Level	...	Straigth	Straight	...	236	236	3,664	1.25	...
19.0	267	3,370	Level	...	Straight	Straight	...	242	242	3,128	1.07	...
20.0	243	2,900	Level	...	Straight	Straight	...	248	248	2,652	0.91	...
21.0	225	2,600	Level	...	Straight	Straight	...	254	254	2,346	0.80	250
22.0	209	2,300	+0.37	216	Straight	Straight	...	261	477	1,823	0.62	...
23.0	195	2,.070	+0.37	216	Straight	Straight	...	267	483	1,587	0.54	...
24.0	182	1,850	+0.37	216	Straight	Straight	...	273	489	1,361	0.46	...
25.0	172	1,700	+0.37	216	Straight	Straight	...	280	496	1,204	0.41	...
26.0	163	1,550	+0.37	216	Straight	Straight	...	286	502	1,048	0.36	...
27.0	**155**	**1,410**	+0.37	216	Straight	Straight	...	292	508	902	0.31	...
27.5	150	1,340	+0.37	216	Straight	Straight	...	296	512	828	0.28	...
27.25	Coasting	....	+0.37	216	Straight	Straight	...	294	510	....	—0.18	930
27.25	Coasting	....	—1	—585	Straight	Straight	...	294	294	291	0.10	...
22.25	Braking	....	—1	—585	Straight	Straight	...	...	Braking	....	—2.00	...
22.25	Braking	....	—1	—585	Straight	Straight	...	...	Braking	....	...	1,230
22.25	Braking	....	—1	—585	11.5	500	279	262	541	44	...	1,550

determining the points at which the speed is limited and to assist in calculating the combined train resistance.

How the Degree of a Curve is Determined. The values of railway curves are commonly expressed in terms of the central angle subtended by a chord 100 ft. long. Thus a 1-deg. curve is one such that the angle at the center end of the radius is 1 deg. and the radius is $100 \times 360 \div 2\pi = 5730$ ft. The radius in feet for any curve is therefore to $5730 \div$ degrees of curvature.

A convenient form for tabulating the various values is shown in Table II, which gives the figures obtained for the first part of the run. The speed-time graph is plotted by using these values as described in my previous articles. The graphical method of W. S. Valentine referred to in Chapter XXVII is a great convenience in a case such as this, and in Fig. 41 is shown this method as applied to the problem we are considering. From these graphs the acceleration at any speed on any grade may be read direct.

At the beginning of the run the track is straight and level for 250 ft. and the train accelerates at a rate of 1.57 m.p.h.p.s. to a speed of 14.2 m.p.h. when all resistance is cut out. The point *A*, Fig. 41, shows this speed and *K* the corresponding acceleration. From this point, *A* the speed is increased to 16.7 m.p.h., point *B*, using the full field of the motors and the rate of acceleration decreases from *K* to *L*. The change to the permanent field is then made and the acceleration rate increases to 1.55 m.p.h.p.s. as shown at *M*.

The speed now increases from *C* to *D* and the acceleration rate decreased from *M* to *N*. At this point the train reaches the 0.37 per cent grade and the rate of acceleration is then indicated by the line *RYPU* which is obtained as follows: When a train is operating on a grade, it is equivalent to having the net tractive effort decreased by the amount of the grade resistance. The amount of the grade resistance per motor in this case is $(117{,}000 \text{ lb.} \times 0.0037) \div 2$ or 216.5 lb. This value is laid off to the right of the point *O* as shown by *OY*. A straight line drawn through *Y* parallel to *ONLMK* will be the required acceleration graph on this grade. The train continues to increase in speed from the point *D* (Fig. 41) to the point *E*, which corresponds to a speed of 27.5 m.p.h. on the speed-net

tractive-effort curve, and the rate of acceleration decreases from the point U to the point P.

Slowdowns Must Be Made for Short-Radius Curves. As the train is now approaching a 500-ft.-radius curve, the speed must be decreased to $\sqrt{500}$ or 22.3 m.p.h. Power is accordingly shut off and the train coasts for four seconds before the brakes are effective. The rate of retardation while coasting is found by projecting the point H corresponding to 27.5 m.p.h. on the train resistance-speed graph to the point R on the acceleration graph. This rate of retardation is found to be 0.18 m.p.h.p.s. After four seconds the brakes are applied and the speed of the train decreases to 22.3 m.p.h. When the train reaches the 1 per cent down grade the increased tractive effort from this grade is more than the train resistance at that speed, so that the train would accelerate if the brakes were not kept applied. It is thus necessary to keep the brakes on until the rear of the train is around the curve. Power is then again applied and the train accelerates to a speed of 37 m.p.h. when it is again necessary to reduce the speed to 15 m.p.h. to take a crossover.

In order to determine when the train reaches a certain grade or curve some method for determining the distance traveled must be used. As already pointed out in a previous article, the area under the speed-time graph is a measure of the distance traveled. The speed-time graph can be plotted and the area measured until it is found to be just sufficient to correspond to the required distance, or a distance-time graph can be plotted at the same time as the speed-time graph. A method of determining the distance-time from the speed-time graph is as follows:

How a Distance-Time Graph Is Plotted. The speed-time graph is divided into increments corresponding to a certain increase or decrease in speed. It is assumed that the average speed of the train during this time is equal to one-half the initial and final speed and the distance which the train would travel at this average speed in the length of time taken is computed. Thus referring to Fig. 42 we find that twenty-three seconds from the start the train has a speed of 25 m.p.h. and at twenty-six seconds the speed is 26 m.p.h. The average speed for these three seconds is 25½ m.p.h. or 37.4 ft. per second. The distance traveled will then be 3×37.4 or 112.2 ft. The smaller the in-

crements taken the greater will be the accuracy of the calculations. Usually the same increments can be used as are taken in plotting the speed-time graph, and the two graphs can then be carried along together. In Fig. 42 the distance-graph is shown constructed.

TABLE III—DETERMINATION OF EQUIVALENT GRADE FOR A RUN WITH GRADES OF VARIOUS LENGTHS

Per Cent Grade	Length of Grade, Feet	Rise in Feet	Fall in Feet
Level	250	....	....
+0.37	680	2.516	....
—1.00	700	....	7.000
—0.45	260	....	1.170
+0.44	670	2.948	....
+0.26	565	1.469	....
—0.38	490	....	1.862
Level	200	....	....
—0.30	1,120	....	3.360
—1.80	1,450	....	26.100
Level	360	....	....
Total.........	6,745	6.933	39.492

(39.492 ft. — 6.933 ft.) ÷ 6,745 ft. = 0.48 per cent Equivalent Grade.

Some engineers prefer to plot a speed-distance graph as an aid in determining where to stop the construction of the speed-time curve for a given grade or curve so as to conform to the conditions governing operation on the new grade or curve. In laying out signals a speed-distance graph is necessary since the spacing of the signals will depend on the distance required to stop the train from the speed at which it is traveling. Speed-time curves provide a method for determining the power and energy consumed in a given service and speed-distance curves, aside from their use in connecting up different portions of runs, also give information of particular value to the operating engineer since they show the speed at every portion of the distance. A speed-distance graph with distance plotted as the horizontal element resembles a speed-time graph in appearance, as will be seen by referring to Fig. 42. The straight line portions of the speed-time graph when the accelerating and retarding force is constant become parabolic curves in the speed-distance graph. This has led to many graphical methods being worked out for obtaining these curves, many of which possess considerable

merit. I find the method of determining distance by measuring the area under the speed-time graph the most convenient.

How Equivalent Grade Is Determined. To illustrate how the uniform grade for any particular run or series of runs is determined I will calculate this for the particular run under consideration in this article. The average or equivalent grade for any section of track connecting two points is the ratio of the difference in elevation of these two points to their distance apart measured in the same units. The accompanying Table III shows a convenient method for tabulating the various steps of the calculation. The distance that the track rises or falls for each grade is computed and from this the total difference in elevation of the ends of the run is determined. This value divided by the total distance apart of the points gives the equivalent grade which is usually expressed in per cent. The use of the equivalent grades in plotting speed-time curves assumes that the energy stored in the train as a result of down grades may be used to furnish the tractive effort necessary in addition to that supplied by the motors of the train to ascend a following up grade.

The amount of energy available as a result of such grades will, of course, depend on the amount of braking necessary on the down grades to prevent excessive speeds being attained and will also be affected by the location of the stops or stations on the line with respect to the grades.

CHAPTER XXX

INCREASED ECONOMY RESULTS FROM CORRECT OPERATION OF CAR EQUIPMENT

It is the duty of a good motor designer to determine all the factors of possible waste in the equipment he is designing and endeavor to eliminate or reduce them. The operation of the motors involves some losses that cannot be avoided, but all can be kept at a minimum by correct operation, and much energy can be saved by careful and efficient operators.

The energy wasted in car operation includes the losses in the grid resistors, the iron and copper losses in the motors during acceleration and the energy absorbed in braking which is dissipated as heat in the brakeshoes and wheels. The useful energy is that which is used in overcoming train resistance, including the resistance due to grades and curves. In considering the means available for reducing the power necessary in operating a car over a definite run at a certain schedule speed, the effect of varying the different cycles of operation will be shown. The accelerating cycle which forms the first part of every run extends from the starting of the car through the period in which it is brought into motion. The ultimate speed of a car depends on the duration of this accelerating period and the grades or curves encountered. The efficiency obtained during the accelerating period depends on the waste in energy and time that takes place.

The aim of control designers is to provide for increasing the car speed at as nearly a uniform rate as possible in the shortest time consistent with current peaks, wheel slippage and comfort of the passengers. Such a consideration is quite independent of the manner of manipulation of the apparatus.

The only way in which a designer can control manipulation is by making the apparatus automatic in its functioning. The accelerating force is a certain constant amount to which impulses are added as the various steps of the starting resistors are cut out. For any given average rate of acceleration the same

amount of energy is wasted in the car resistors every time the car is started and the controller is brought to the full parallel

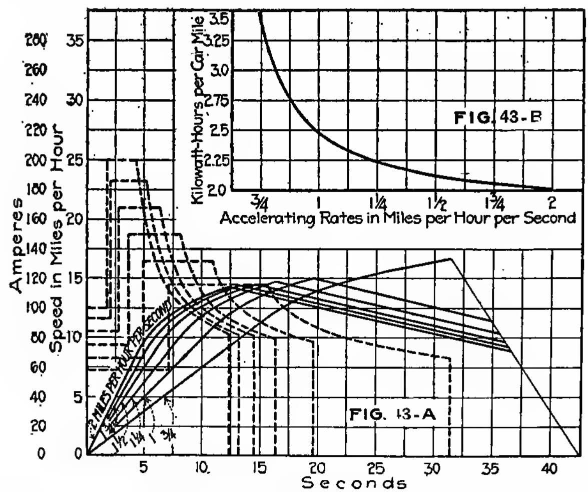


FIG. 43-A—INFLUENCE OF VARIOUS RATES OF ACCELERATION ON THE POWER INPUT OF A CAR

FIG. 43-B—RELATION BETWEEN POWER INPUT PER CAR-MILE AND ACCELERATING RATES IN MILES PER HOUR PER SECOND

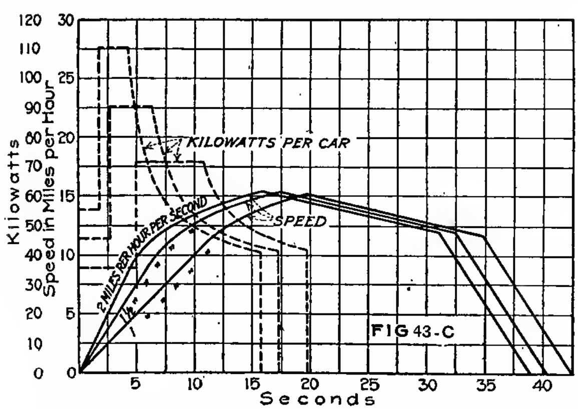


FIG. 43-C—EFFECT OF VARIOUS RATES OF ACCELERATION ON THE SCHEDULE SPEED MADE BY A CAR

position. This is entirely independent of the length of the run, the number of stops per mile, the rate of braking, or the length of stop. As the length of the run increases this constant rheo-

static loss becomes a smaller percentage of the total power used. It is thus on short runs that the economy of rapid acceleration is most apparent. As a study of the effect of different rates of acceleration on the energy input for a car operating under average conditions I have plotted the several graphs shown in Fig. 43-A, for rates of acceleration of ¾, 1, 1¼, 1½, 1¾ and 2 m.p.h.p.s. The operating conditions assumed are the same as those already given in this series of articles, and are for a 23.56-ton car making a run of 620 ft. at a schedule speed of 8½ m.p.h. with a 7.2 second stop, the rate of braking being taken at 1½ m.p.h.p.s. The results are given in Table I.

TABLE I—COMPARISON OF ENERGY TAKEN WITH DIFFERENT RATES OF ACCELERATION

				Kilowatt-Hours			
Acceleration Rate M.p.H.p.S.	Speed at Which Last Resistance Step Is Cut Out, M.p.H.	Rheostatic Accelerating Period, Seconds	Total Accelerating Period, Seconds	For Rheostatic Accelerating Period	For Total Accelerating Period	Per Car-Mile	Per Cent Power Saving Over Rate of ¾ M.p.H.p.S.
¾	11.65	15.5	13.3	0.210	0.4012	3.42	...
1	10.79	10.8	19.7	0.167	0.2896	2.47	27.8
1¼	10.05	8.0	16.3	0.139	0.2648	2.23	34.8
1½	9.49	6.3	14.5	0.124	0.2502	2.12	38.0
1¾	8.92	5.1	13.2	0.116	0.2400	2.04	40.3
2	8.55	4.8	12.3	0.101	0.2377	2.02	40.9

The difference in energy saving is considerably less between the higher rates of acceleration than it is between the lower rates. For example, the saving through accelerating at 1 m.p.h.p.s. instead of ¾ m.p.h.p.s. is 27.8 per cent, while the saving through acceleration at 2 m.p.h.p.s. as against 1¾ m.p.h.p.s. is only 0.1 per cent.

To illustrate this decreased variation the graph shown in Fig. 43-B has been constructed, with varying rates of acceleration plotted against the energy per car-mile required. It will be noted that there is a "knee" in the graph between the 1 and 1¼ m.p.h.p.s. points, and for rates higher than this difference in energy saving is comparatively small.

In this particular case it appears that the economic limit of

acceleration is reached at about 1½ m.p.h.p.s., and the small additional economy that results from a higher rate of acceleration would more than likely be offset by the increased cost of maintaining the equipment and the resulting decreased comfort of passengers.

Referring to the graphs in Fig. 43-A we find that when accelerating at the low rate of ¾ m.p.h.p.s. it is necessary to operate the car without coasting in order to make the schedule speed of 8½ m.p.h. This, of course, could not be done in regular service, so that the average rate of acceleration must be higher than ¾ m.p.h.p.s. if the desired schedule is maintained.

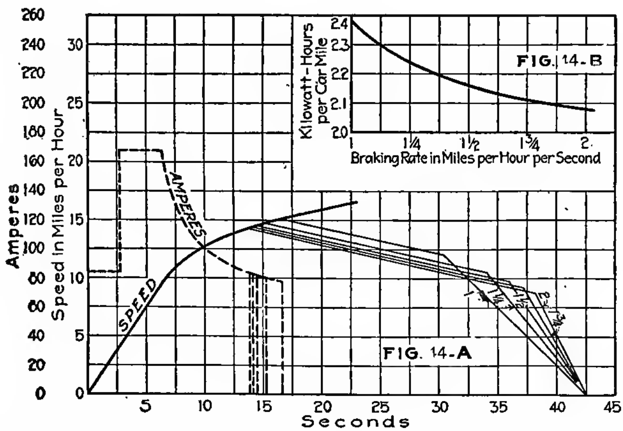


FIG. 44-A—COMPARISON OF POWER INPUT FOR A CAR OPERATED WITH VARIOUS RATES OF BRAKING. FIG. 44-B—RELATION BETWEEN POWER INPUT PER CAR-MILE AND THE BRAKING RATE IN MILES PER HOUR PER SECOND

Further Economies Result from Increasing Schedule Speeds with Rate of Acceleration. In making these comparisons of energy taken for various rates of acceleration, the point should not be lost sight of that we are considering that the cars and equipment have a definite service to perform. Other advantages of a higher rate of acceleration can be obtained by increasing the schedule speeds as the rate of acceleration is increased. This, of course, takes more power, so the saving results from operating fewer cars to perform the same service, and is shown by the decreased cost of platform expense as well as by a small total saving in power.

To show the economies that may be expected in this direction I have plotted the graphs shown in Fig. 43-C for the same equipment used for the previous graphs. The rates of acceleration taken are 1, 1½ and 2 m.p.h.p.s. and the basis for determining the point at which power is cut off is arrived at by making the number of seconds consumed in coasting equal to the speed in miles per hour at the point of cut-off. Thus, when accelerating at a rate of 1 m.p.h.p.s. the point of cut-off is 15.1 m.p.h. and the car is allowed to coast for 15.1 seconds before the brakes are applied. This method of making the amount of coasting in seconds equal to a constant times the speed in miles per hour at cut-off is very convenient for comparing runs of different lengths at different schedule speeds, and the results obtained for a continuous run with various stops by using this method will approximate very closely to the service obtained from a typical run.

To make certain that the continuous current rating of the motors is not exceeded, a typical run should be laid out and the speed-time and power-input graphs plotted. The ratio of the amount of coasting in seconds to the speed at cut-off in miles per hour for this typical run will be the constant desired.

Operating Cost Decreases as Acceleration Rate Increases. In Table II the resulting operating cost for three different rates

TABLE II—EFFECT OF THREE RATES OF ACCELERATION ON SCHEDULE SPEED AND OPERATING COSTS

Acceleration Rate M.p.H.p.S.	Schedule Speed, M.p.H.	Energy Kilowatt-Hours per Car-Mile	Car-Hours for 40,000 Car-Mile Operation	Platform Wages at 60 Cents per Car-Hour Plus 10 per Cent	Power Cost at 1½ Cents per Kilowatt-Hour	Total Cost	Per Cent Saving
1	8.5	2.47	4,706	$3,105.96	$1,482.00	$4,587.96	..
1½	8.9	2.44	4,494	2,966.04	1,464.00	4,430.04	3.5
2	9.2	2.39	4,348	2,869.68	1,434.00	4,303.68	6.2

of acceleration are shown for comparison. To illustrate the annual saving it may be assumed that each car will operate 40,000 miles during the year, that the average platform expense will be 60 cents per car-hour plus 10 per cent, and that the cost of energy at the car will be 1½ cents per kilowatt-hour. A

total saving of $157.92 per car per year is obtained by increasing the rate of acceleration from 1 to 1½ m.p.h.p.s. and the schedule speed from 8.5 m.p.h. to 8.9 m.p.h. The total saving per car per year obtained by an increase in acceleration from 1 to 2 m.p.h.p.s. and increasing the schedule speed of from 8.5 to 9.2 m.p.h. is $284.28, or 6.2 per cent. If we consider a single line 8 miles long operating a service at five-minute intervals, this would take twenty-four cars at a schedule speed of 8.5 m.p.h. and twenty-two cars at 9.2 m.p.h., or a saving of two cars for the line. We thus see the advantages which are to be gained by keeping the accelerating rate up to the maximum consistent with the equipment operated.

A High Braking Rate Reduces the Power Input. To illustrate how the energy input varies with different braking rates, the graphs shown in Fig. 44-A have been plotted. These are made on the basis of accelerating at 1½ m.p.h.p.s. and results are shown for rates of retardation of 1, 1¼, 1½, 1¾ and 2 m.p.h.p.s. The saving in energy is obtained by cutting off power sooner and coasting to a lower speed before applying the brakes to produce a higher rate of retardation.

Fig. 44-B is a graph for the various braking rates plotted against the energy required to make the run. As in the accelerating graph, Fig. 44-B, we see that there is a "knee" in this curve beyond which the energy saving is comparatively small. The "knee" in the retardation graph, however, is less pronounced than that in the accelerating graph. In actual service for surface lines it has been found that the most economical braking rate lies between 1½ and 2¼ m.p.h.p.s., depending on the characteristics of the equipment and the service operated. Beyond this it is better to consider careful handling of the equipment and the comfort of passengers in preference to the slight additional economies that result.

With Shorter Stops Smaller Motors Can Be Used. The number and length of stops are two factors of prime importance in car operation. They determine, in a measure, not only the size of the motors but also the energy consumed, the schedule speeds obtained, the number of cars necessary for a given service, and the capacity of the line and power house. This is one of the largest fields for operating economies that can be found in electric railway operation to-day. In my article in the *Elec-*

tric Railway Journal of April 20, I showed how the number of stops affects the schedule speeds and really forms an operating characteristic for the selection of the motors. The duration of stop is determined largely by car design, by the size and type of doors, steps and platforms, and by the efficiency of the operating crew. A very little confusion will lengthen a stop from two to three seconds. In the service that we are considering, with eight and one-half stops per mile and a run of 8 miles long, 6.8 minutes would be lost in a round trip by increasing the average length of each stop three seconds. This would necessitate using an additional car on the line, and when the cost of the power used for operating this car, together with the additional cost of the platform wages is figured, a good idea of the effect of a few seconds at each stop can be obtained.

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